Weapons Systems of the FUTURE

TOOLS OF THE TRADE FOR THE SCI-FI WRITER

BY LINK MILLER

Why you need this class

Writer's Perspective: If you have ANY military or weapons in your story, you must get the facts right or your credibility is shot.

No matter what you are writing or will eventually write about, you need a strong foundation and knowledge of weapons systems.

If you have a weapons scene without this basic foundation, your readers may catch you out on lack of veracity.

All information in this brief is from **UNCLASSIFIED** sources

Background

I am a 27 yr. veteran (retired Lt Colonel) of the US Marines.

I have served all over the US and the world. I am a trained expert in everything from hand weapons, assault helicopter operations, and Air Defense & Space Tactics. I was the USMC rep for non-lethal weapons development, a professional war gamer, and I spent my last 8 years on Air Force bases doing Space & Missile Defense.

Areas we will cover

- Near future (10-25 years)
- Far future (25+)
- Non-Lethal (NLW)
- DARPA (Defense Advanced Research Projects Agency)
- Air
- Sea
- Land
- Air
- Space
- Communications (good/bad)
- Reality VS Hollywood

Near Future

What is ‘near’ future as it applies to weapons?

The near future is a world which is imminently real – one of which we can have no definite knowledge, which exists only imaginatively and hypothetically, but which is nevertheless a world in which (or something like it) we may one day have to live, and towards which our present plans and ambitions must be directed.

The fears and hopes reflected in our images of the near future are real, however over pessimistic or over optimistic they may seem.

1 – 10 years (Think of how long it takes to field a new system)

Far future

What is the far future as it pertains to weapons?

- The far future tends to be associated with notions of ultimate destiny, and is dominated by metaphors of senescence; its images display a world irrevocably transfigured.

It is viewed from a detached viewpoint; the dominant mood is – paradoxically – one of nostalgia, because the far future, like the dead past, can be entered only imaginatively, and has meaning only in terms of its emotional resonances.

- 10 - 25 + years

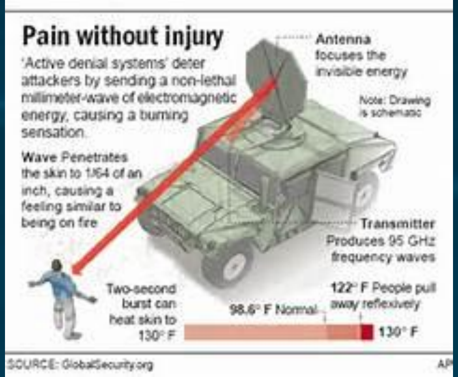
DARPA

(Defense Advanced Research Projects Agency)

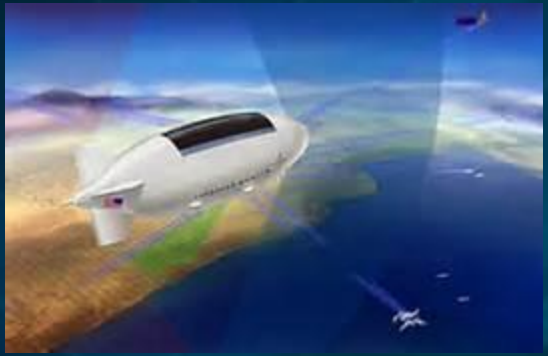
The Defense Advanced Research Projects Agency is an agency of the U.S. Department of Defense responsible for the development of emerging technologies for use by the military. DARPA was created in February 1958 as the Advanced Research Projects Agency by President Dwight D. Eisenhower.

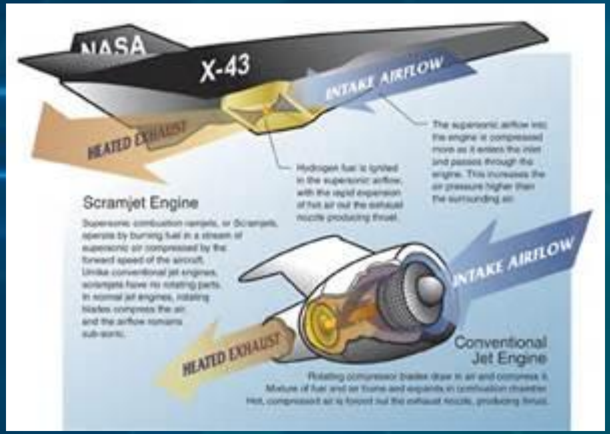
Non-Lethal Weapons

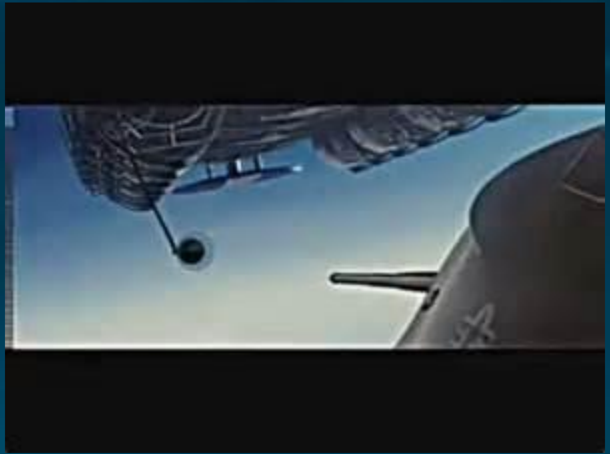
- AKA known as less-than-lethal
- Active Denial System (The Fentonizer)
- Anti-traction material (Bad example-sticky foam)
- TASER Shotgun
- PHASR (Yes, real phasers… set on stun, duh)
- Incapacitating Flashlight
- Speech Jammer



AIR – small, medium, and large







Fast Lightweight Autonomy (FLA)

Small, fast, agile unmanned vehicles that can operate in tight spaces indoors was recently tested sensor-laden quadcopters that managed to avoid obstacles while hitting their target speed on 20 meters per second (about 45 miles per hour).

The goal behind FLA is to give dismounted soldiers a view inside buildings, especially in urban areas, and do it with a minimum of involvement by drone operators. FLA is working to develop algorithms that will allow small drones to operate independently, gathering images and data inside a building without an operator, who might have other things to do, having to control their every movement.

Aurora Excalibur

The Aurora Excalibur is an unmanned aircraft that operates with a vertical take off and landing. It can reach speeds of 460 miles per hour and carry cargo or onboard missiles. The aircraft is operated by remote control.

The Excalibur was **successfully tested in June of 2009.**

VTOL X-Plane

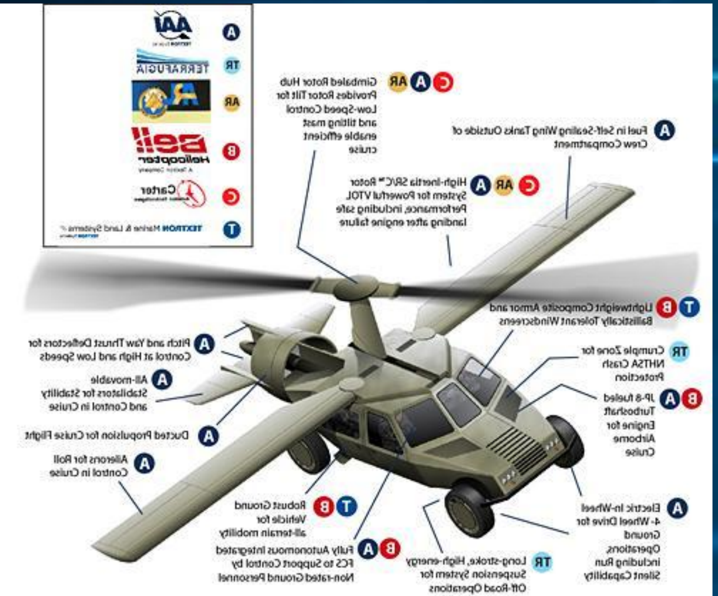
Through a hybrid of fixed-wing and rotary-wing technologies, DARPA is looking at a plane that can efficiently take off and hover like a helicopter and fly at high-speeds like an aircraft. This project is currently exploring unmanned aircraft, but the technology can apply to manned aircraft as well.

From this… to this

FLYING CARS (It's about time)

DARPA's Transformer TX 'flying Humvee' project

The Transformer TX project calls for four-man vehicle that drives like a jeep and then takes off to avoid roadside bombs (or impress the ladies).



Actually, why bother driving at all?

FUTURE VTOL

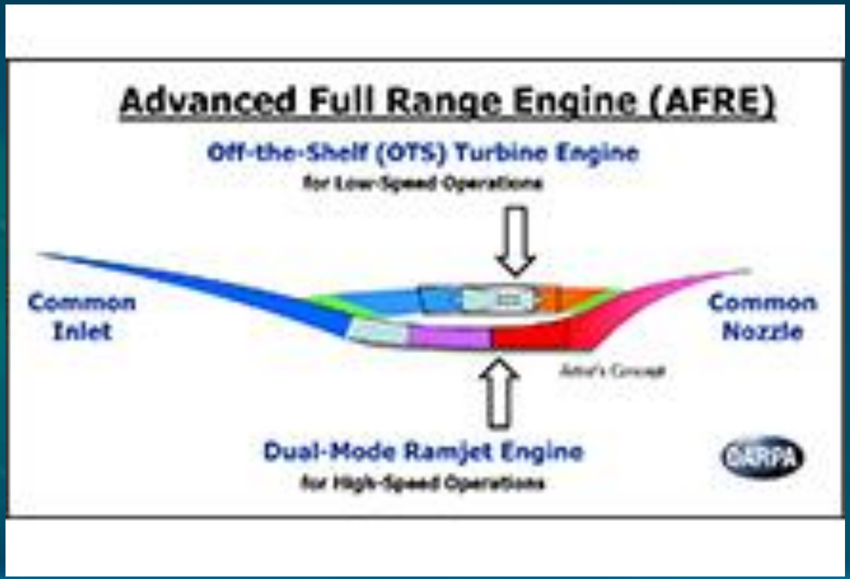
The traditional problem with VTOL aircraft has been the tremendous complexity involved in having to transition from horizontal flight to vertical flight and the incredible downwash forces.

FYI Fan-in-Wing were pretty much the least successful of all the VTOL approaches attempted by NASA and the DOD over the past 60 years.

Advanced Full Range Engine (AFRE) Program

Hybrid Propulsion System is paving the way to routine, reusable hypersonic flight.

In the decades-long quest to develop reusable aircraft that can reach hypersonic speeds—Mach 5 (approximately 3,300 miles per hour) and above—engineers have grappled with two intertwined, seemingly intractable challenges: The top speed of traditional jet-turbine engines maxes out at roughly Mach 2.5, while hypersonic engines such as scramjets cannot provide effective thrust at speeds much below Mach 3.5.



HAA (High Altitude Airships)

An untethered, unmanned lighter-than-air vehicle that will operate above the jet stream in a geostationary position to deliver persistent station keeping as a surveillance platform, telecommunications relay, or a weather observer.

Unmanned, powered airship that can maintain a relatively geostationary position at 70,000 feet. Lift is provided by helium that is contained in its envelope. Differential thrust, electric-powered props control the pitch and roll and keep it in position. With the advent of thin-film photovoltaic solar cells (capable of producing voltage when exposed to radiant light), commercially available fuel cells, and lightweight/high-strength fabrics.

High Energy Liquid Laser Area Defense System (HELLADS)

The Pentagon's Defense Advanced Research Projects Agency (DARPA) is developing the future of lasers weapons known as High Energy Liquid Laser Area Defense System. The goal of this laser system is to be compact enough to fit on board of a tactical aircraft without affecting mission performance. The lasers would be powerful enough to shoot down rockets, missiles, and artillery shells.

LASERS

US Army will have laser weapons by 2023 as research bosses say killer technology is "very close."

Initial trials of laser weapon revealed "unprecedented power" of system

First demonstrations expected to take place in 2020

Team now building full powered unit for lab tests

Land

Men, armor, and weapons

Robots & drones

Mech (walkers, rollers, and things that go BOOM!)

Kinetic & non-kinetic weapons

New Medical Unit - drones and bio readers

DARPA Jetpack

Gives soldiers speed of Flash…well, not really

Arizona State University is developing a jetpack, but rather than help the wearer fly, it is designed to help them run faster. The 4MM, or 4 Minute Mile, project is being funded by DARPA.

It aims to help every wearer, eventually every soldier, be able to easily run a four-minute mile without exerting too much energy.

Testers have shaved 30 seconds off their time even while wearing the 11 pound jet pack.

Body Armor

Clothing worn by military and police personnel to protect against gunfire or shrapnel.

BATTLE SUITS (Starship Trooper Style)

Tactical Assault Light Operator Suit (TALOS) is the Main Powered Suit of the Mobile Infantry (MI).

There are several hard points on the armor, allowing it able to be attached with various optional equipment and weapons, such as a small missile launcher or a combat knife. On each elbow, there is a large hard point, which is made per standards of a tank and a fighter jet. Weapons can be place on the rack on the back. Two jump jets are mounted in the lower back of the armor. They will open when in use.

Each helmet has a searchlight mount on its left and a infrared camera on the right side. There are four camera-eyes on the visor that provide the image of outside, displayed on the other side of the visor. There is a HUD system inside the helmet.

SIPES - Soldier Integrated Precision Effects Systems

Along with the ability to fire new lightweight telescoped ammunition, and a secondary effects module that adds either a three-round 40mm grenade launcher or a 12-gauge shotgun, there is also a NATO-standard power and data bus to allow the attachment of smart accessories, such as electro-optical sights and position sensors that connect to command and control networks.

EXACTO – Laser Guided Bullet

The EXACTO 50-caliber round is claimed to be the first ever guided small-caliber bullet. The maneuverable projectile uses a real-time optical guidance system to change its path mid-flight and home in on a target, potentially overcoming adverse weather and hostile conditions to improve sniper accuracy (2 miles).

LAND - Weapons

XM-25 Grenade Launcher

The XM-25 is capable of firing up to 25 grenades at any distance that can be predetermined and programmed by the user.

This new weapon combines the capabilities of both a gun and a computer in one. It is rumored that five XM-25 guns **were used in Afghanistan.**

Invisibility (E-Camouflage)

Heated via electrical stimulation, the sharp temperature gradient between the cloak and the surrounding area causes a steep temperature gradient that bends light away from the wearer.

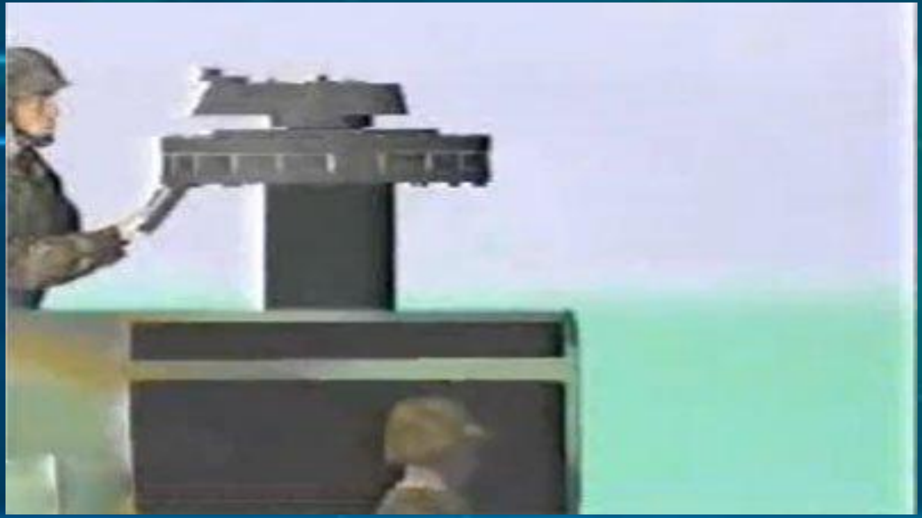
Metamaterials: tiny structures that are smaller than the wavelength of light. If properly constructed, they guide rays of light around an object -- much like a rock diverting water in a stream.

Projection skin – projects what is behind subject onto front.

DREAD Silent Weapon System

The DREAD Silent Weapon System has the ability to shoot 120,000 rounds per minute.

The gun runs fully on electrical energy, not gunpowder, which means no recoil, no sound, and no heat. **Debut date unknown.**



Ground X Technology (GXV-T)

Today's ground-based armored fighting vehicles are better protected than ever, but face a constantly evolving threat: weapons increasingly effective at piercing armor. While adding more armor has provided incremental increases in protection, it has also hobbled vehicle speed and mobility and ballooned development and deployment costs.

To help reverse this trend, DARPA's Ground X-Vehicle Technology (GXV-T) program, recently awarded contracts to eight organizations, promises nimbler, faster, smarter armored ground vehicles.

MEDEVAC

- Retrieve
- Scan
- EMT
- Dustoff

Sea

- Surface vessels
- Drones
- Rail guns
- Lasers
- Stealth

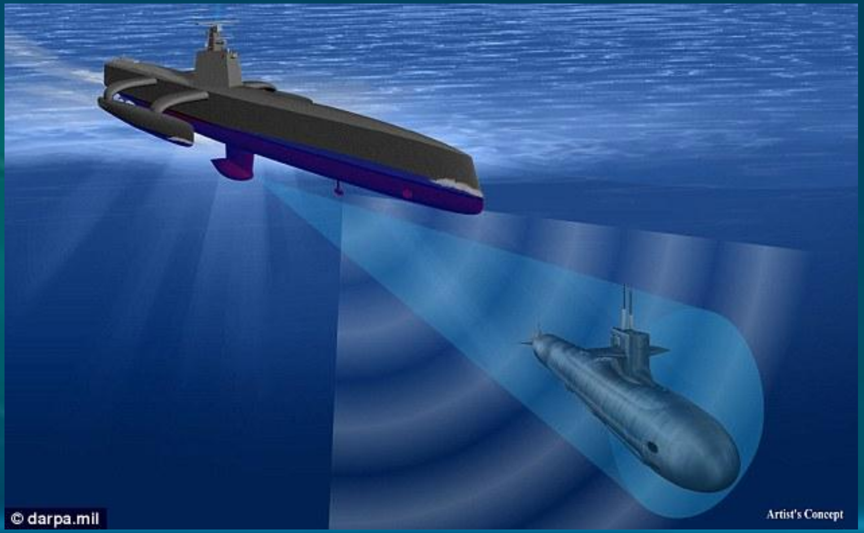
SEA -The Free Electron Laser

The Navy is in the process of designing another laser system to shoot down rockets and missiles that may attack its ships. There are endless uses for the laser when it's not shooting down enemy fire, such as a tracker, sensor, information exchange, and target designation among others.

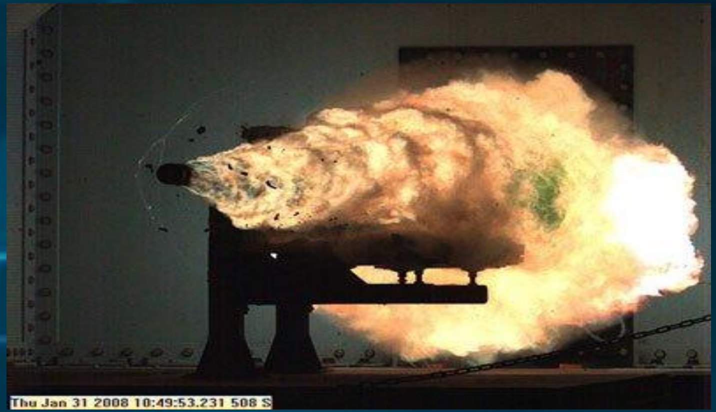
Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV)

The first 132-foot long ship, to be used for counter-mine missions, reconnaissance and resupply, took to the water on April 7th. The Anti-Submarine Warfare The ACTUV will be able to operate for several months at a time scouring the seas and coastal areas for silent, diesel powered enemy submarines.

The test boat was able to tail a target boat at 1 km distance, something military bosses say is a major step forward.

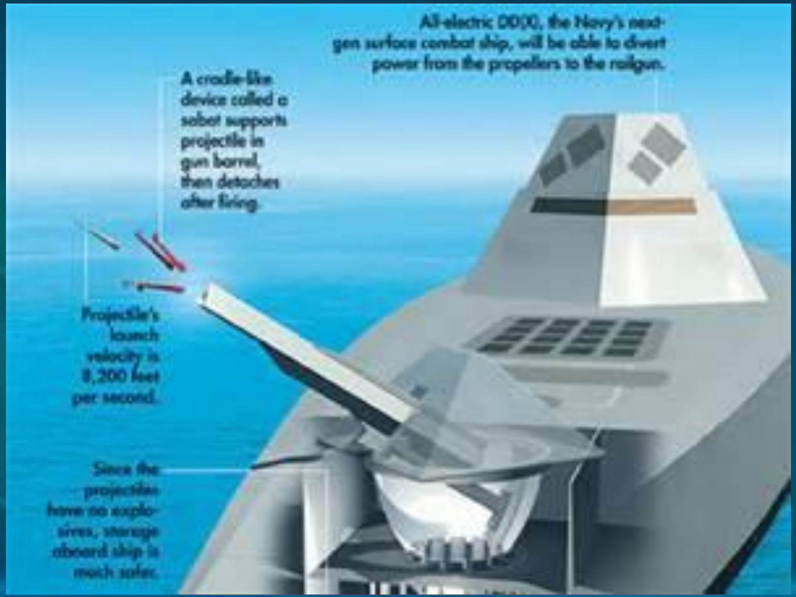


Land & Sea - Electromagnetic Rail Guns



EM rail gun launchers use a magnetic field rather than chemical propellants (e.g., gunpowder or fuel) to thrust a projectile at long range and at velocities of 4,500 mph to 5,600 mph, seven times the speed of sound.

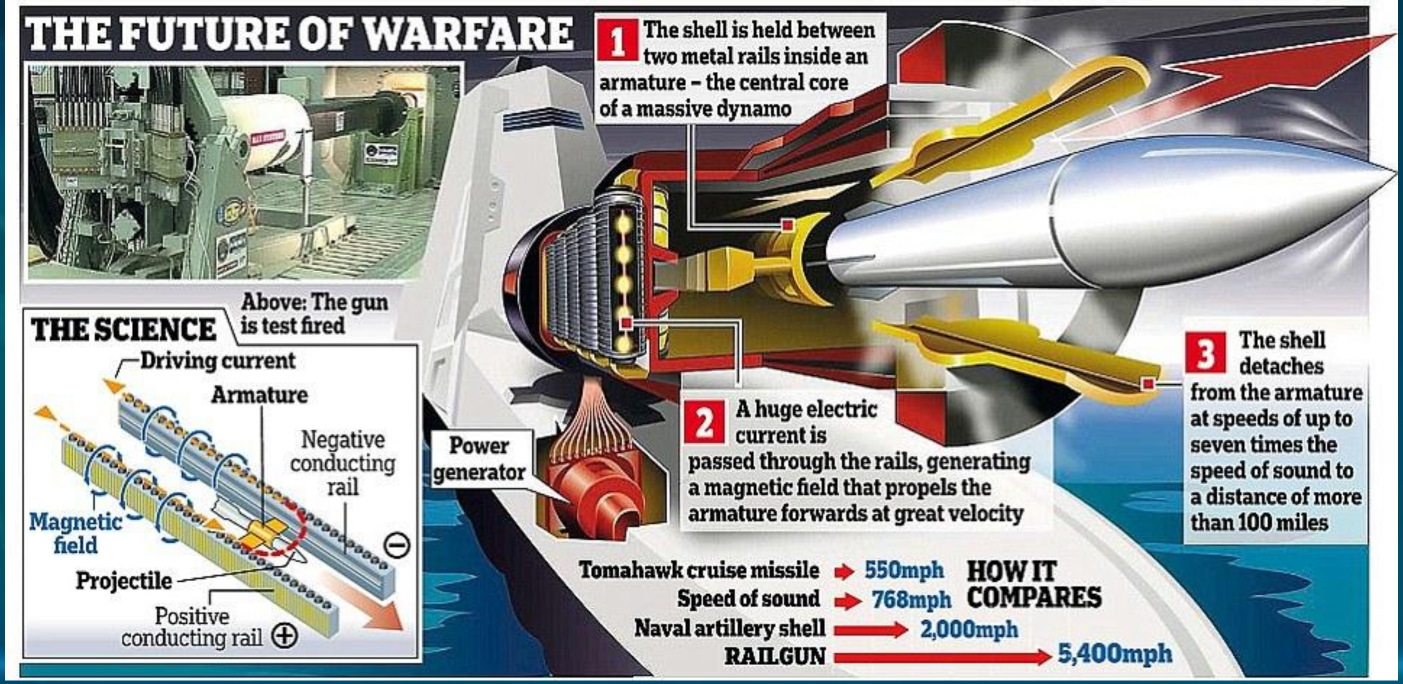
A perfected version of the gun is expected to be ready by **2025.**



RAIL GUNS (how they work)

A radical new weapon that can fire a shell at seven times the speed of sound could be used by the Navy as soon as 2018. Described as 'Star Wars technology' by researchers, the rail gun can fire a shell weighing 10kg at up to 5,400mph over 100 miles. It does this with such force and accuracy it penetrates three concrete walls or six half-inch thick steel plates.

Development of a futuristic weapon is going well enough that a Navy admiral wants to skip an at-sea prototype in favor of installing an operational unit aboard one of its new Zumwalt-class destroyers.



Space… the final frontier, especially for combat

- An extremely harsh environment
- Surveillance, communications systems
- Weapons: kinetic and non-kinetic

If you are writing in the far future 100+ years, feel free to have phasers, shields, and warp drive otherwise physics still apply

SPACE

Micro-satellites

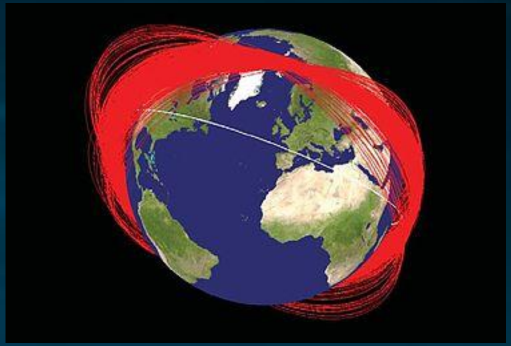
EMPs

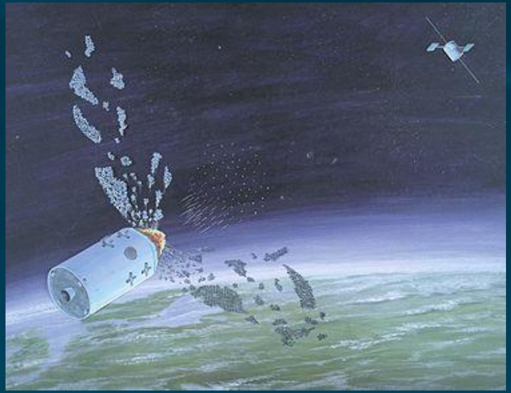
Lasers (Beams not Bolts)

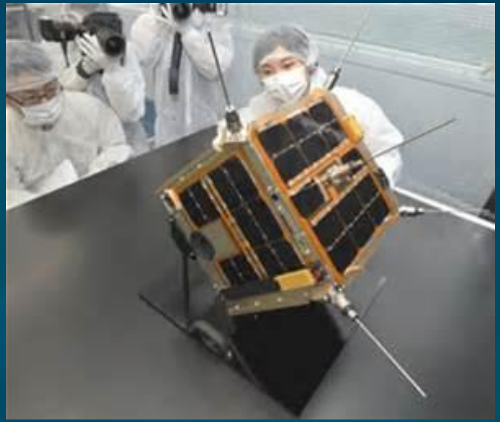
ASATs (2 types: orbital vs direct ascent)

Rail Guns (The real rods from the gods)

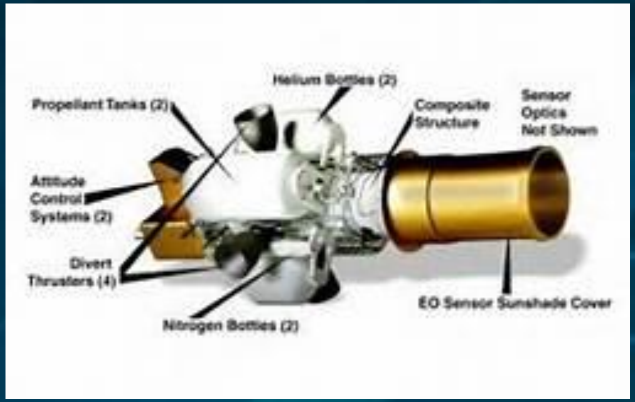
Dog Fights (Pac Man vs Top Gun)







Space



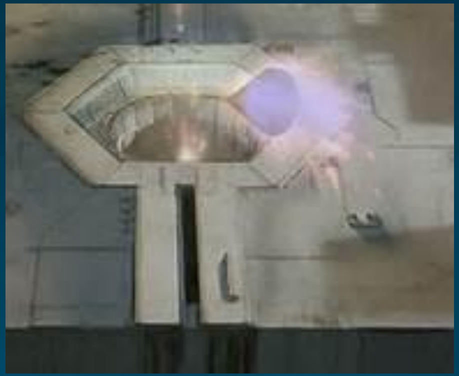
Kinetic vs non-kinetic

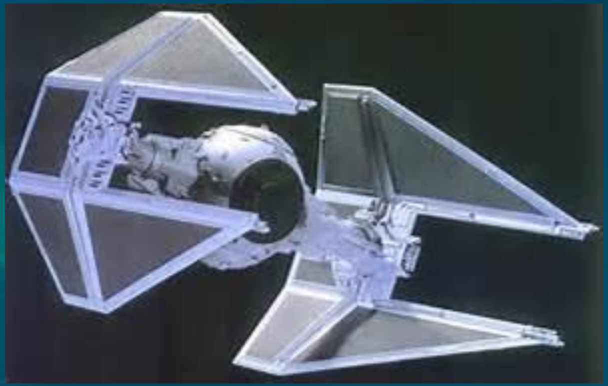
Today – KKV, Anti-satellite missiles

Tomorrow – lasers, particle beam

Future – phasers, disruptors, plasma cannons, photon (or proton) torpedoes,

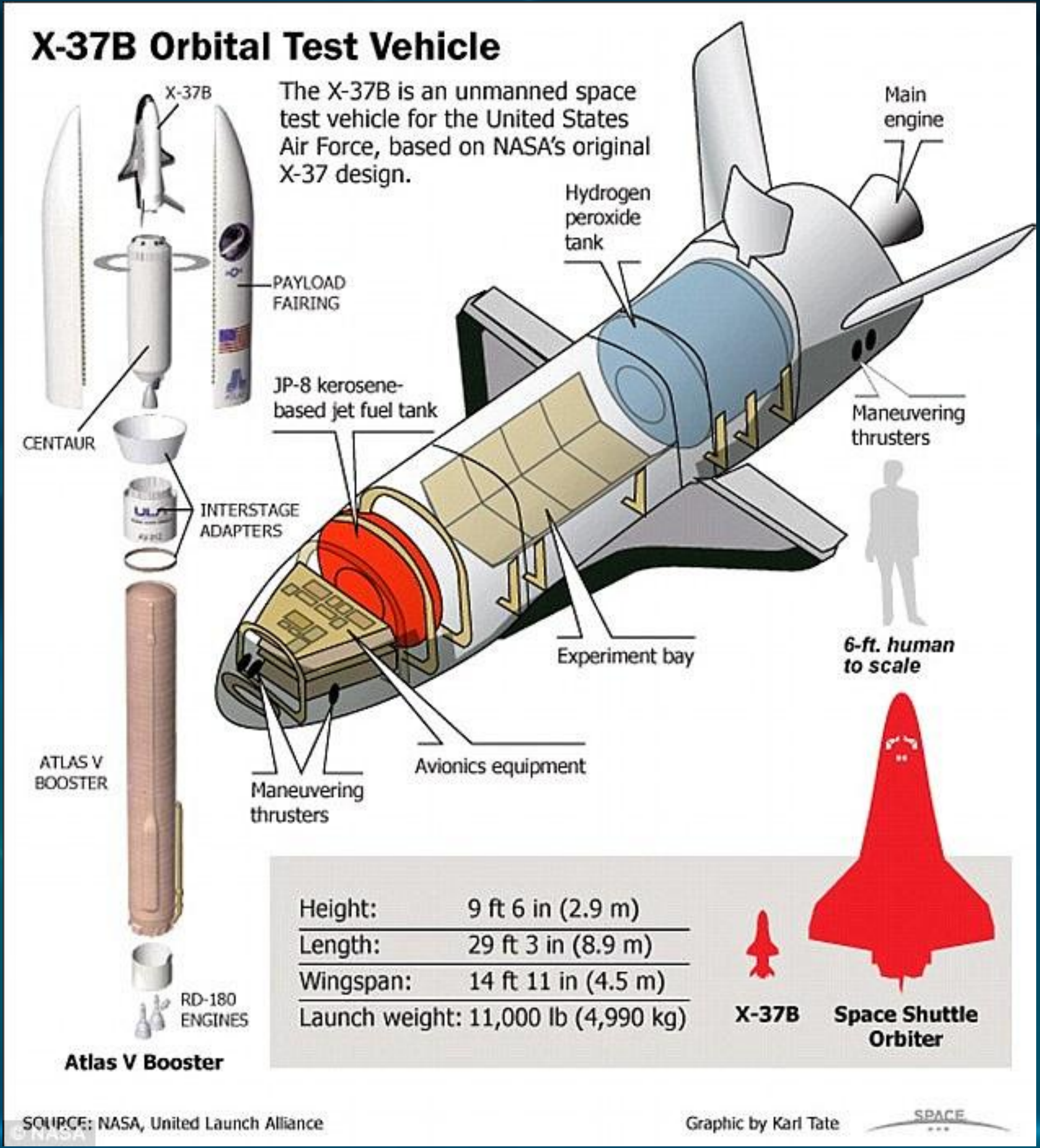
Remember, physics still apply. And there are no aerodynamics in space.





X-37B

Like a shuttle, X-37B is blasted into orbit by a rocket. However, it lands using a runway like a normal aircraft. The X-37B is too small to carry people onboard, but does have a cargo bay similar to that of a pickup truck, which is just large enough to carry a small satellite



XS-1(Experimental Spaceplane 1)

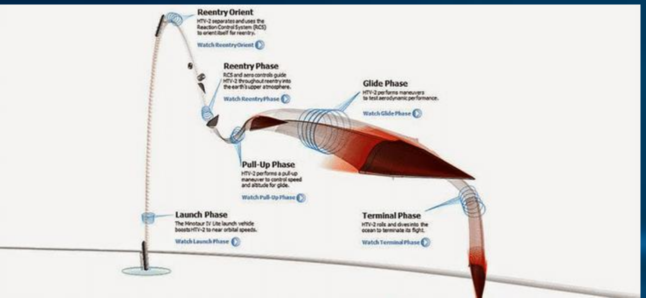
DARPA created its Experimental Spaceplane (XS-1) program with the major goal to reuse the spacecraft frequently, with a proposed launch rate of 10 missions in just 10 days.

The XS-1 is envisioned to heft payloads for less than $5 million a flight, each weighing between 3,000 and 5,000 lbs. (1,360 to 2,267 kilograms). The aircraft-like craft is also supposed to fly faster than Mach 10, or 10 times the speed of sound.

Hypersonic Cruise Missiles

After the terrorist attacks of September 11th 2001, American officials decided that they needed to obtain a “prompt global strike” capability to deliver superfast or “hypersonic” unmanned vehicles that can strike quickly by flying through the atmosphere, and cannot be mistaken for a nuclear missile.

The US is working on two kinds of hypersonic missiles. One is a boost glide system that rides a rocket into space, then reenters the atmosphere and glides to its target at up to 14,000 miles per hour. The other is an air-breathing missile, a close cousin to the ramjet, that scoops up oxygen as it flies a flatter, Mach-10 path to its destination.



Orbital Outlook

Orbital Outlook integrates the largest and most diverse network of space sensors ever to help avoid collisions in space.

More than 500,000 pieces of manmade space debris—including spent rocket stages, defunct satellites, and fragments as small as flecks of paint—currently hurtle around the Earth at roughly 17,000 mph.

At those speeds, impacts involving even the smallest of those items can damage satellites and spawn chain reactions of collisions, increasing the amount of orbital flotsam and creating “minefields” in space that can remain impassable for centuries.

Missile Defense

The Missile Defense Agency's (MDA) mission is to develop, test, and field an integrated, layered, ballistic missile defense system (BMDS) to defend the United States, its deployed forces, allies, and friends against all ranges of enemy ballistic missiles in all phases of flight.

Space

Communications

In the movie *Contact* – radio signal (TV) took how long?

Star Trek (TOS) – message/answer from Star Fleet always came too late.

Faster Than Light Travel (FTL)

Mind – Linking?

Distant (Far) Future

Star Trek vs. *Star Wars*

Physics still apply (gravity, Newton, power, material degradation)

Not much chance without warp drive or a star gate

What about that whole time/space differential?

And how are you going to communicate?

Time, Space, Thought

Who knows where we will be in 100 years…

but watch out for SkyNet.

Reality Vs. Hollywood

So much shown in movies and on TV is rubbish.

Think physics, think practically, think logically

Minority Report

VS

DARPA – real time cmd & control

BOLT (Broad Operational Language Translation)

QUESTIONS?

Contact me:

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Yes, AOL… it's easy to remember

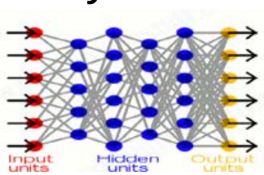
Explainable Artificial Intelligence (XAI)

David Gunning

DARPA/I2O

Explainable AI – What Are We Trying To Do?

AI System



- We are entering a new age of AI applications
- Machine learning is the core technology
- Machine learning models are opaque, non-intuitive, and difficult for people to understand

Watson

AlphaGo

Sensemaking

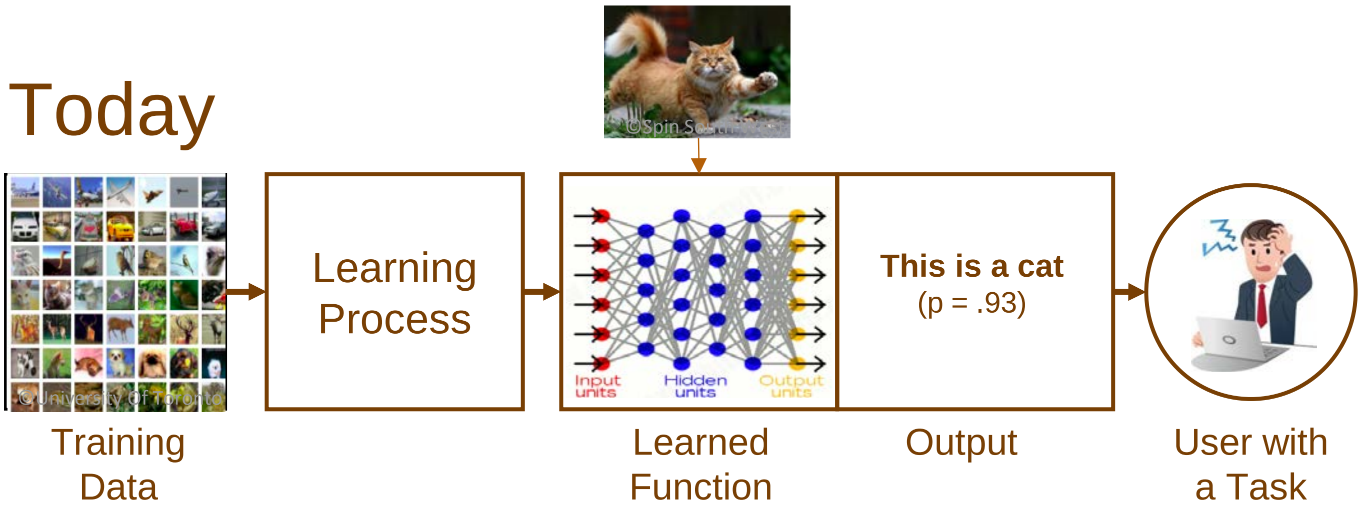
Operations

User

- Why did you do that?
- Why not something else?
- When do you succeed?
- When do you fail?
- When can I trust you?
- How do I correct an error?

Dramatic success in machine learning has led to an explosion of AI applications. Researchers have developed new AI capabilities for a wide variety of tasks. Continued advances promise to produce autonomous systems that will perceive, learn, decide, and act on their own. However, the effectiveness of these systems will be limited by the machine's inability to explain its thoughts and actions to human users. Explainable AI will be essential, if users are to understand, trust, and effectively manage this emerging generation of artificially intelligent partners.

Explainable AI – What Are We Trying To Do?



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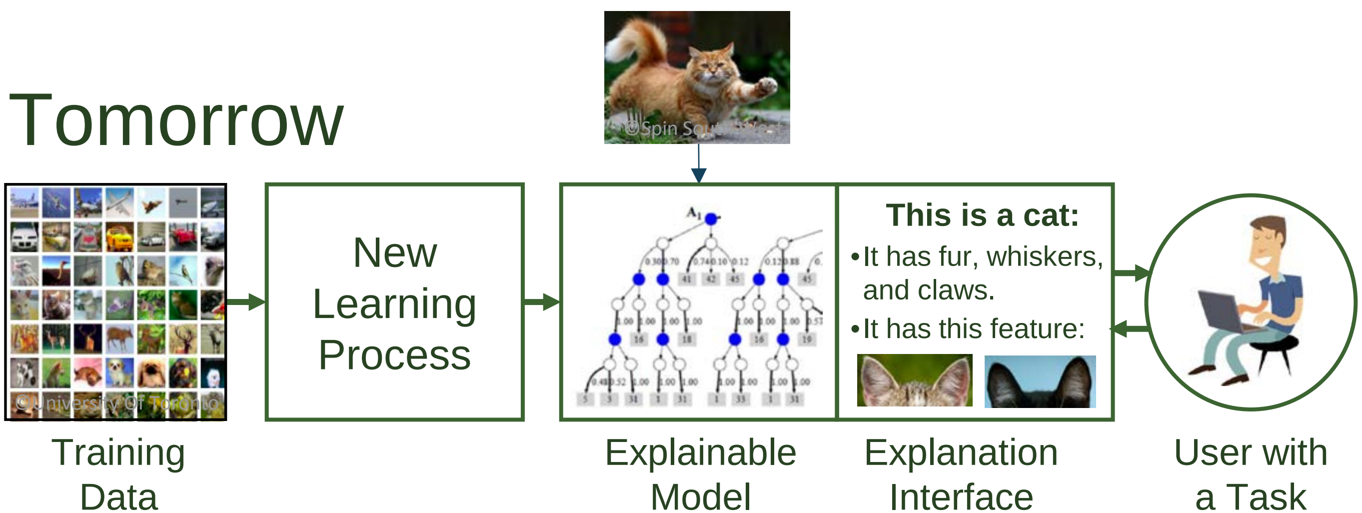


- I understand why
- I understand why not
- I know when you'll succeed
- I know when you'll fail
- I know when to trust you
- I know why you erred

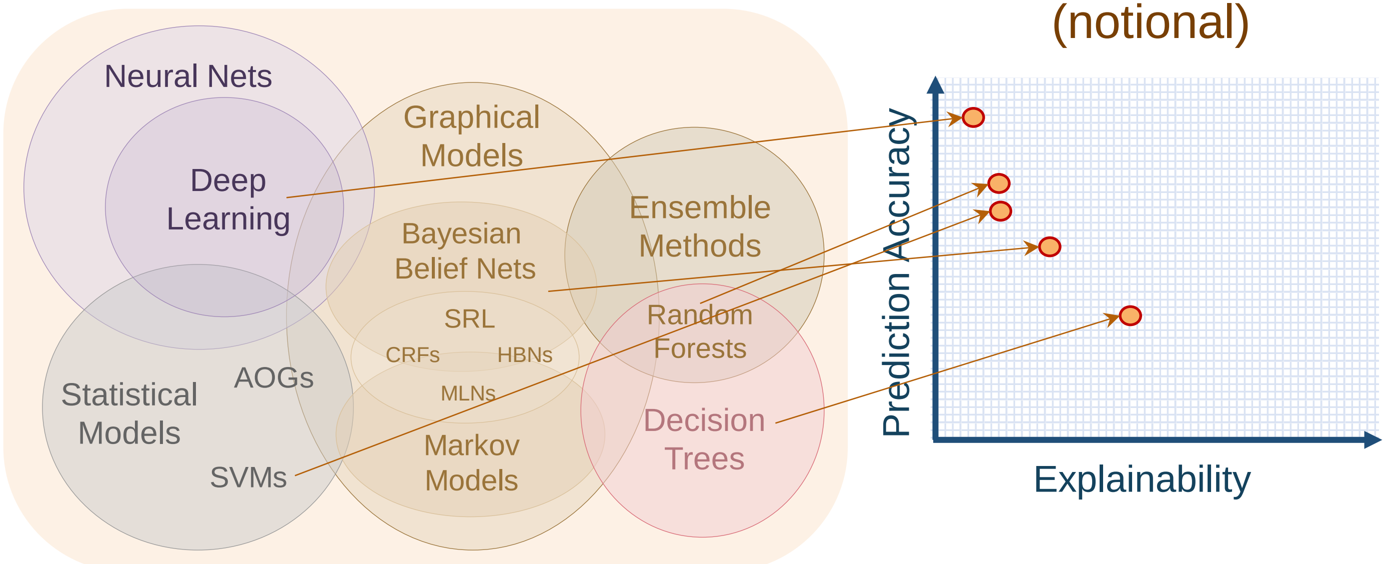
Explainable AI – Performance vs. Explainability

New Approach

Create a suite of machine learning techniques that produce more explainable models, while maintaining a high level of learning performance

Learning Techniques (today)

Explainability (notional)



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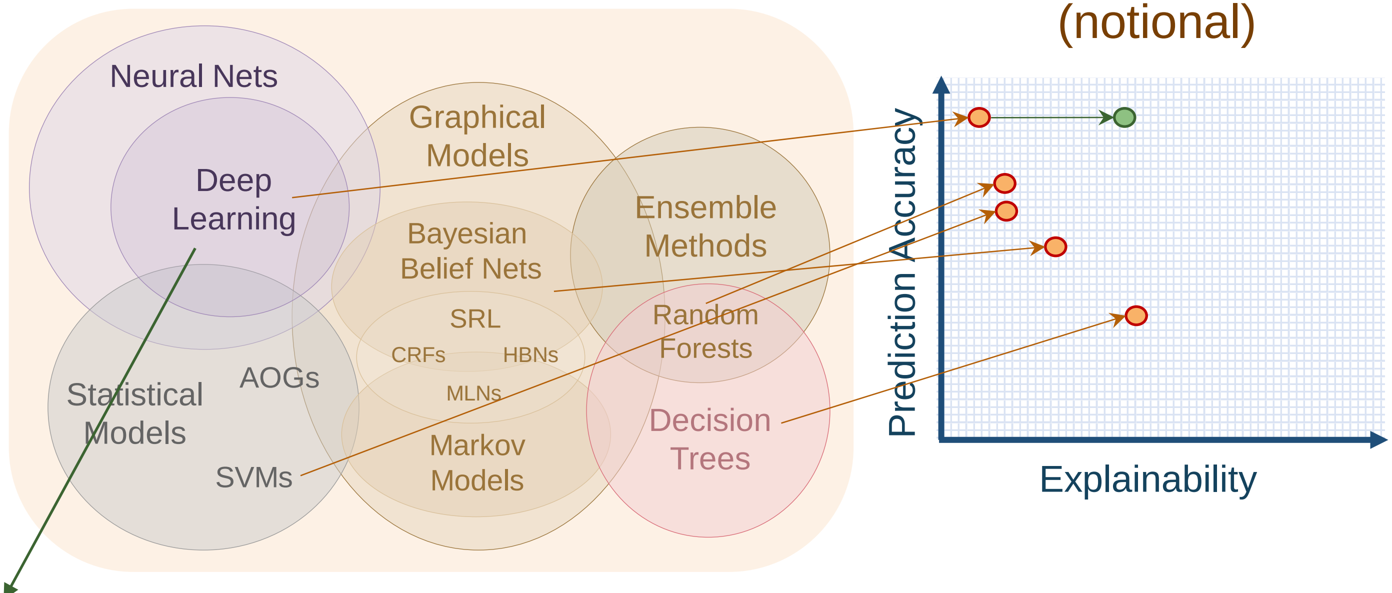
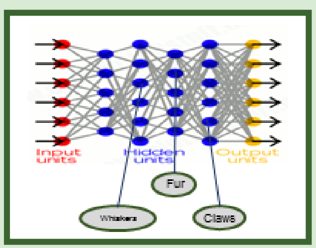


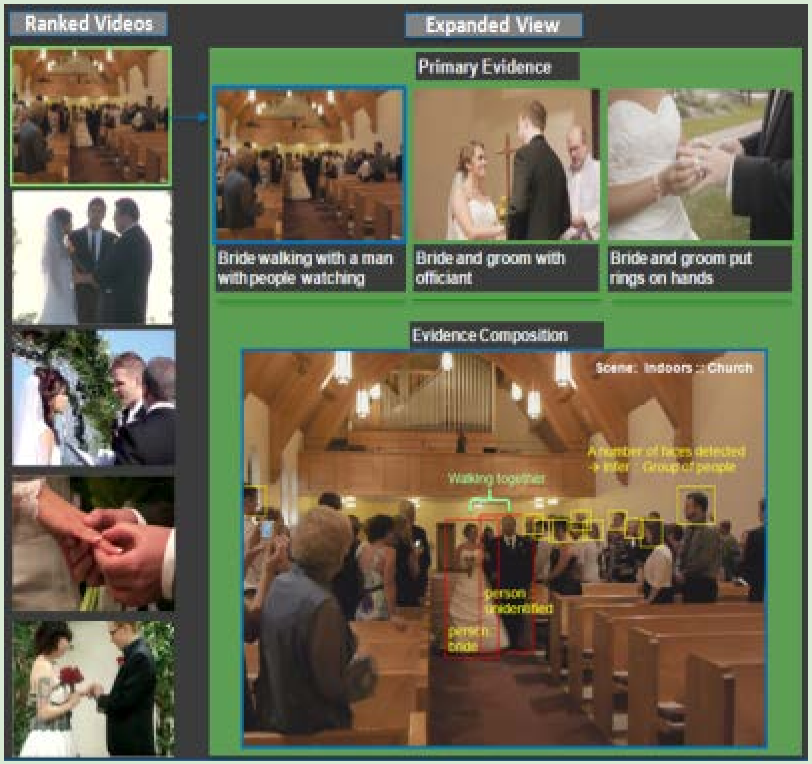


Deep Explanation

Modified deep learning techniques to learn explainable features

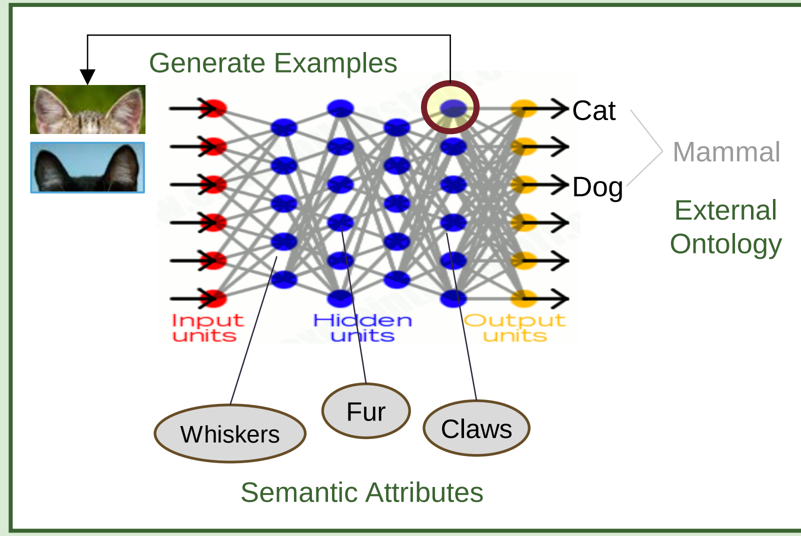
Learning Deep Explanations

Multimedia Event Recounting



- This illustrates and example of event recounting.
- The system classified this video as a wedding.
- The frames above show its evidence for the wedding classification

Learning Semantic Associations

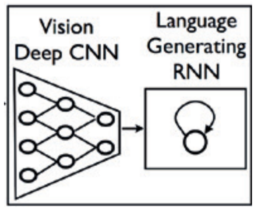


- Train the net to associate semantic attributes with hidden layer nodes
- Train the net to associate labelled nodes with known ontologies
- Generate examples of prominent but unlabeled nodes to discover semantic labels
- Generate clusters of examples from prominent nodes
- Identify the best architectures, parameters, and training sequences to learn the most interpretable models

Cheng, H., et al. (2014) SRI-Sarnoff AURORA at TRECVID 2014: Multimedia Event Detection and Recounting. http://www-nlpir.nist.gov/projects/tvpubs/tv14.papers/sri_aurora.pdf

Learning To Generate Explanations

Generating Image Captions

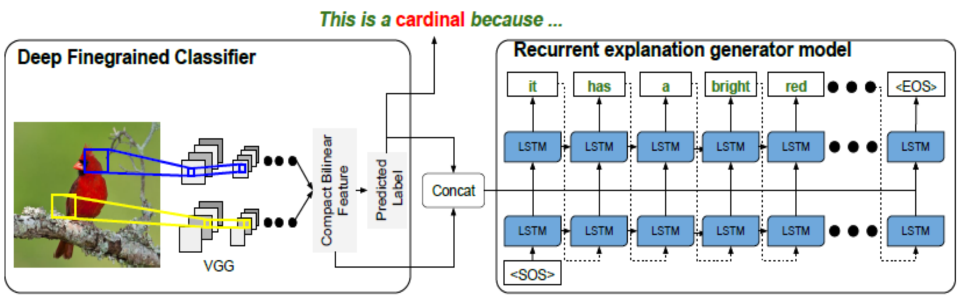


A group of people shopping at an outdoor market

There are many vegetables at the fruit stand

- A CNN is trained to recognize objects in images
- A language generating RNN is trained to translate features of the CNN into words and captions.

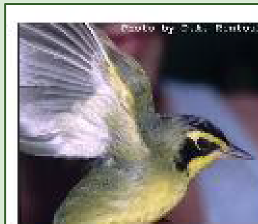
Generating Visual Explanations



Researchers at UC Berkeley have recently extended this idea to generate explanations of bird classifications. The system learns to:

- Classify bird species with 85% accuracy
- Associate *image descriptions* (discriminative features of the image) with *class definitions* (image-independent discriminative features of the class)

Example Explanations



This is a Kentucky warbler because this is a yellow bird with a black cheek patch and a black crown.

This is a pied billed grebe because this is a brown bird with a long neck and a large beak.

Limitations

- Limited (indirect at best) explanation of internal logic
- Limited utility for understanding classification errors

Hendricks, L.A, Akata, Z., Rohrbach, M., Donahue, J., Schiele, B., and Darrell, T. (2016). Generating Visual Explanations, arXiv:1603.08507v1 [cs.CV] 28 Mar 2016

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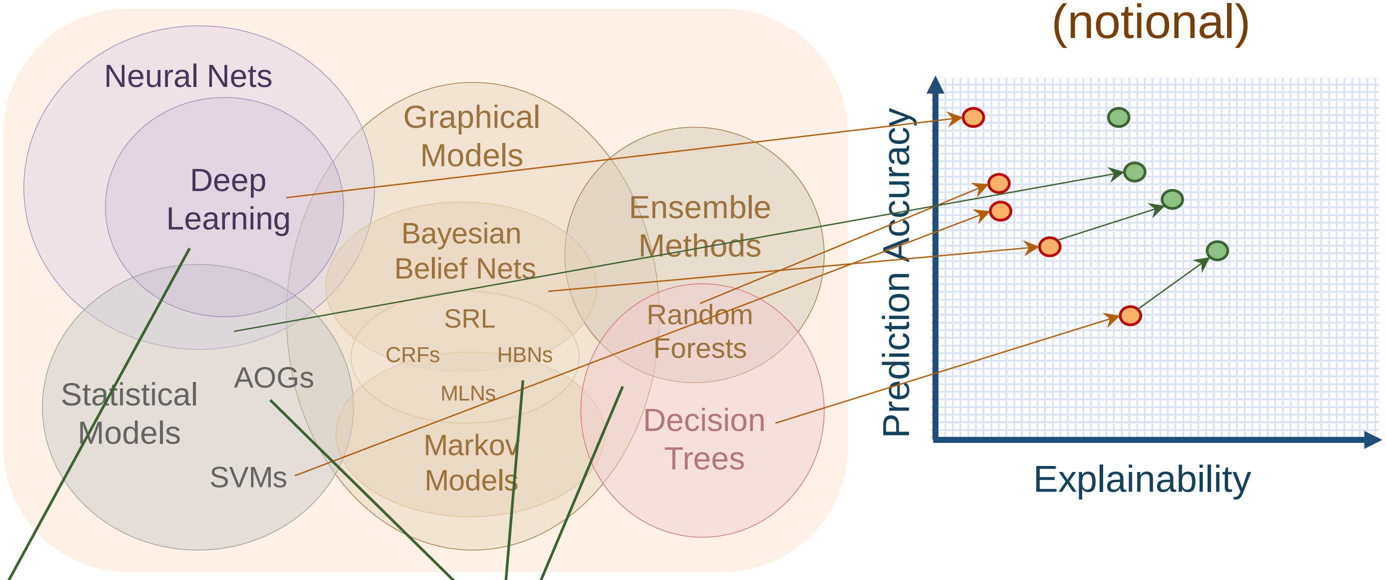
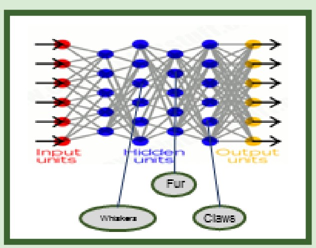
Learning Techniques (today)

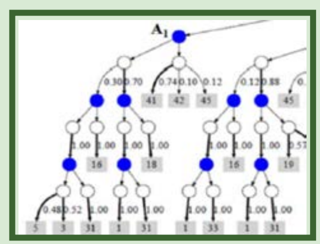
Explainability (notional)





Deep Explanation

Modified deep learning techniques to learn explainable features



Interpretable Models

Techniques to learn more structured, interpretable, causal models

Learning More Interpretable Models

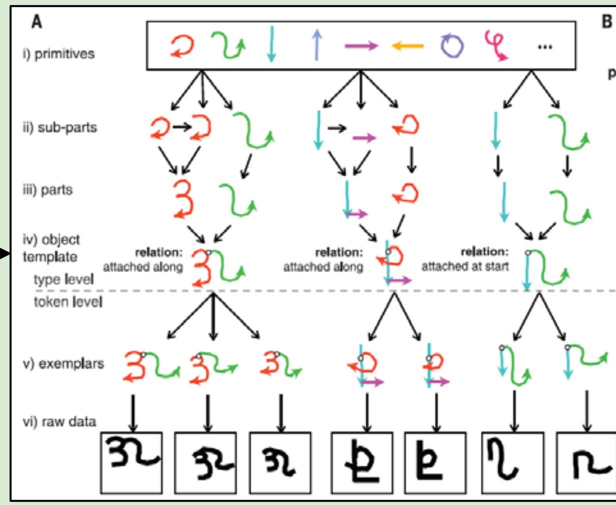
Training Data
1623 Characters

Bayesian
Program
Learning

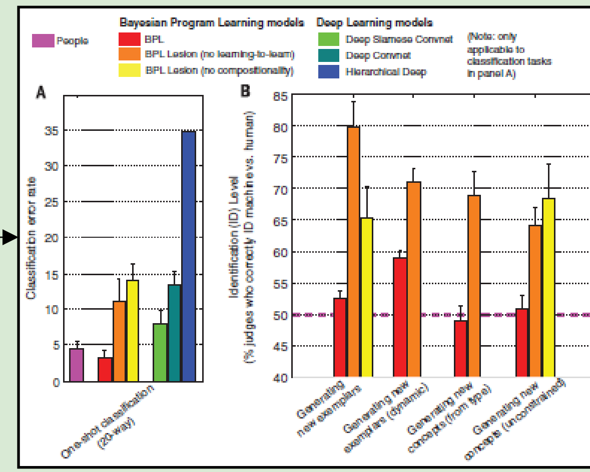
```
num_strokes = Poisson(2)
for i = 1 to num_strokes:
     num_substrokes_prior[i] = Discrete([0,1,1,1,1])
     num_substrokes[i] = Poisson(num_substrokes_prior[i])
     for j = 1 to num_substrokes[i]:
          substrokes[i][j] = substroke_transition_prob[i][j-1]
     relation[i] = relation_prob(substrokes)

for i = 1 to num_strokes:
     noised_substrokes[i][:] = stroke_noise(substrokes[i][:])
     stroke_start_position[i] = start_distribution(relation, t
     trajectory[i] = draw_trajectory(stroke_start_position[i],
AffineTransform = transform_distribution
image = render(AffineTransform(trajectory))
```

Seed Model
A simple Probabilistic Program that describes the parameters of character generation

Concept Learning Through Probabilistic Program Induction



Generative Model
Recognizes characters by generating an explanation of how a new test character might be created (i.e., the most probable sequence of strokes that would create that character)

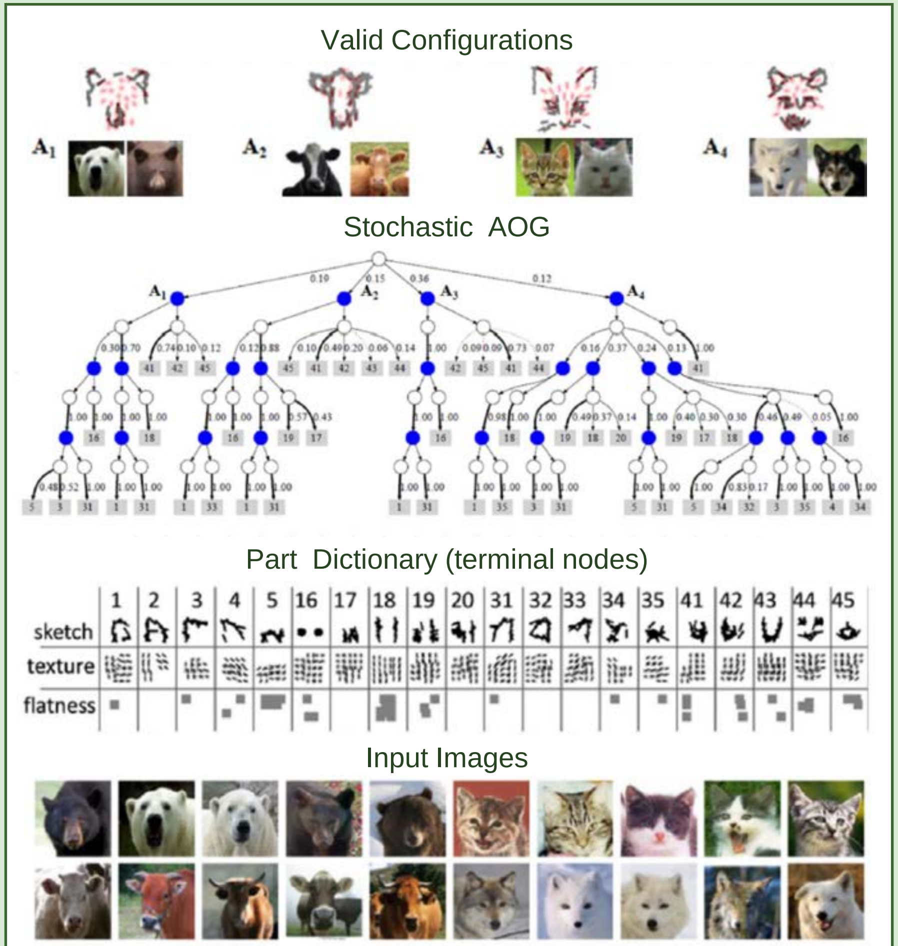


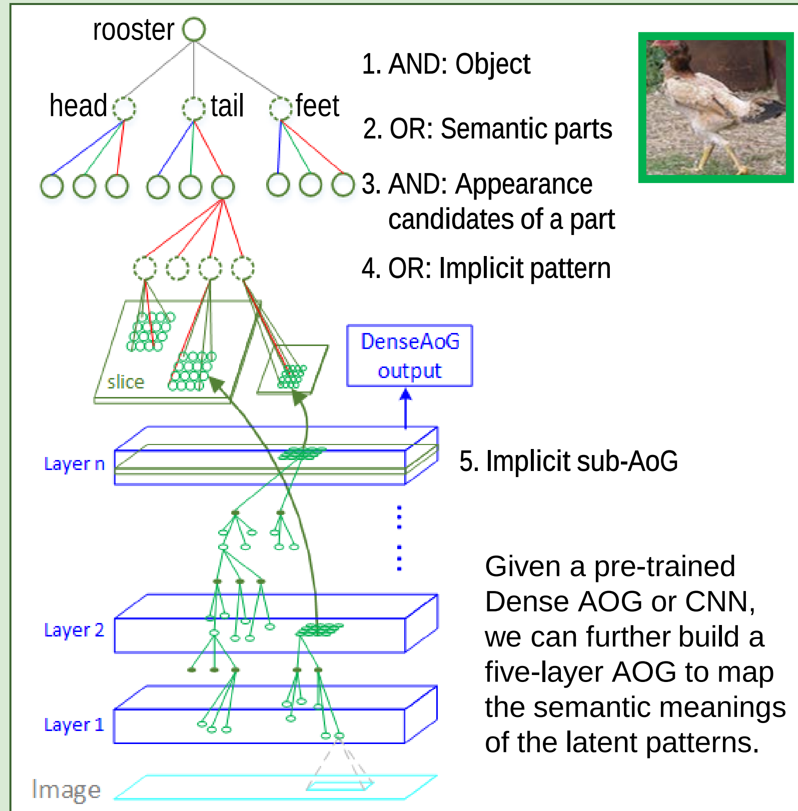
Performance
This model matches human performance and out performs deep learning

Lake, B.H., Salakhutdinov, R., & Tenenbaum, J.B. (2015). Human-level concept learning through probabilistic program induction. *Science.* VOL 350, 1332-1338.

Learning More Interpretable Models

Stochastic And-Or-Graphs (AOG)





Given a pre-trained Dense AOG or CNN, we can further build a five-layer AOG to map the semantic meanings of the latent patterns.

$$L(\theta) = \frac{1}{M}\sum_{m=1}^{M} \underbrace{\log P(I_m, \theta)}_{\text{generative}} + \underbrace{L(pg_m^*, \hat{pg}_m)}_{\text{discriminative}}$$

Si, Z. and Zhu, S. (2013). Learning AND-OR Templates for Object Recognition and Detection. *IEEE Transactions On Pattern Analysis and Machine Intelligence*. Vol. 35 No. 9, 2189-2205.

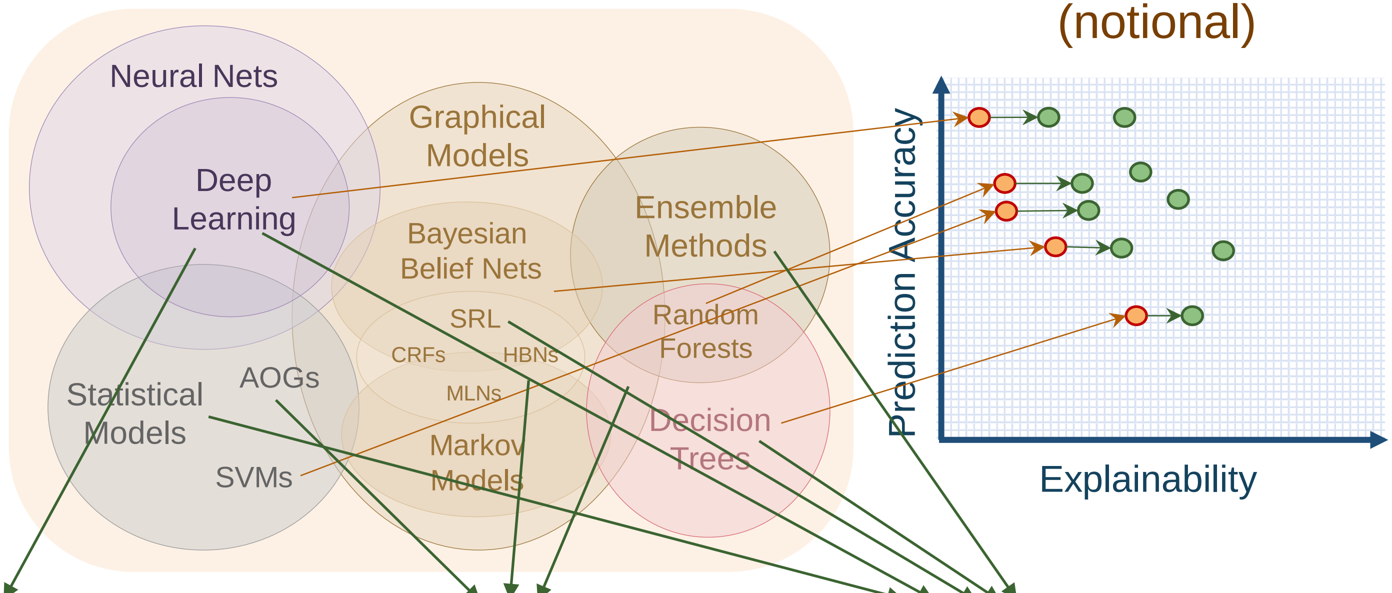
Explainable AI – Performance vs. Explainability

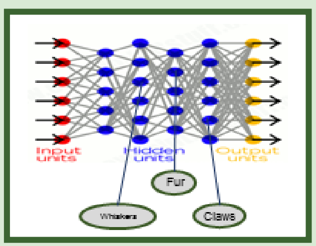
New Approach

Create a suite of machine learning techniques that produce more explainable models, while maintaining a high level of learning performance

Learning Techniques (today)

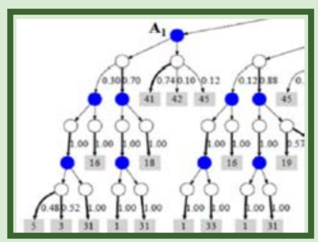
Explainability (notional)





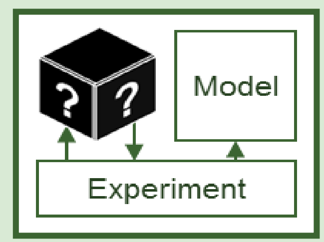
Deep Explanation

Modified deep learning techniques to learn explainable features



Interpretable Models

Techniques to learn more structured, interpretable, causal models



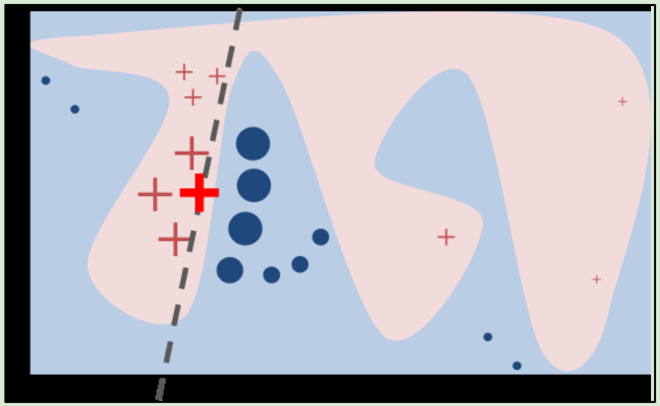
Model Induction

Techniques to infer an explainable model from any model as a black box

Model Induction

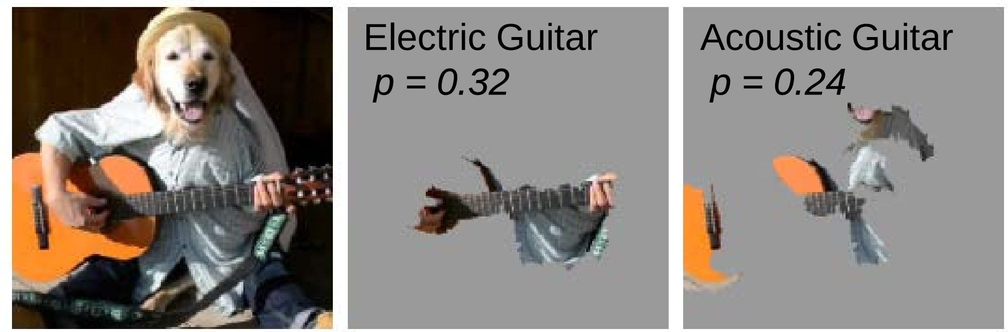
Local Interpretable Model-agnostic Explanations (LIME)

Black-box Induction



The black-box model's complex decision function f (unknown to LIME) is represented by the blue/pink background. The bright bold red cross is the instance being explained. LIME samples instances, gets predictions using f, and weighs them by the proximity to the instance being explained (represented here by size). The dashed line is the learned explanation that is locally (but not globally) faithful. .

Example Explanation



(a) Original Image (b) Explaining *Electric guitar* (c) Explaining *Acoustic guitar*

- **LIME** is an algorithm that can explain the predictions of any classifier in a faithful way, by approximating it locally with an interpretable model.

- **SP-LIME is** a method that selects a set of representative instances with explanations as a way to characterize the entire model.

Ribeiro, M.T., Singh, S., and Guestrin, C. (2016). "Why Should I Trust You?" Explaining the Predictions of Any Classifier. *CHI 2016 Workshop on Human Centered Machine Learning. (arXiv:1602.04938v1 [cs.LG] 16 Feb 2016)*

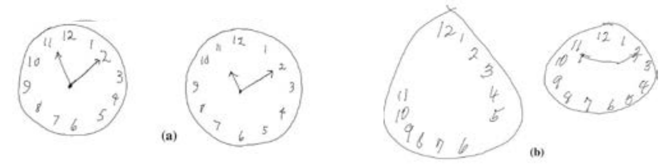
Model Induction

Bayesian Rule Lists (BRL)

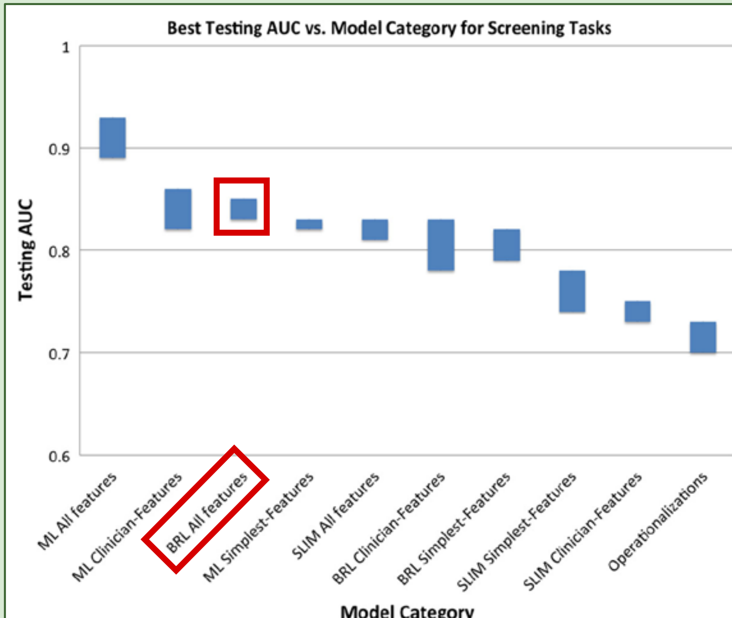
- **if** hemiplegia and age > 60
  - **then** stroke risk 58.9% (53.8%–63.8%)
- **else if** cerebrovascular disorder
  - **then** stroke risk 47.8% (44.8%–50.7%)
- **else if** transient ischaemic attack
  - **then** stroke risk 23.8% (19.5%–28.4%)
- **else if** occlusion and stenosis of carotid artery without infarction
  - **then** stroke risk 15.8% (12.2%–19.6%)
- **else if** altered state of consciousness and age > 60
  - **then** stroke risk 16.0% (12.2%–20.2%)
- **else if** age ≤ 70
  - **then** stroke risk 4.6% (3.9%–5.4%)
- **else** stroke risk 8.7% (7.9%–9.6%)

- BRLs are decision lists--a series of if-then statements
- BRLs discretize a high-dimensional, multivariate feature space into a series of simple, readily interpretable decision statements.
- Experiments show that BRLs have predictive accuracy on par with the current top ML algorithms (approx. 85-90% as effective) but with models that are much more interpretable

Clock Drawing Test

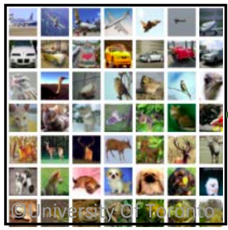


Normal Function | Cognitive Impairment



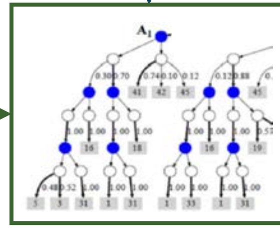
Letham, B., Rudin. C., McCormick, T., and Madigan, D. (2015). Interpretable classifiers using rules and Bayesian analysis: Building a better stroke prediction model. *Annals of Applied Statistics 2015*, Vol. 9, No. 3, 1350-137

Explainable AI – Why Do You Think It Will Be Successful?



Training Data

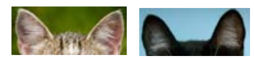
New Learning Process



Explainable Model

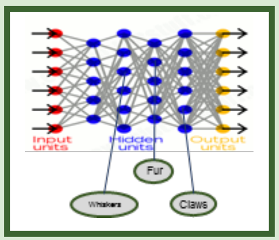
This is a cat:

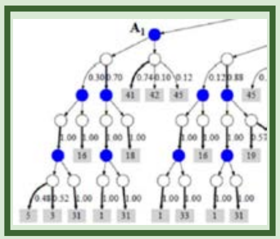
- It has fur, whiskers, and claws.
- It has this feature:

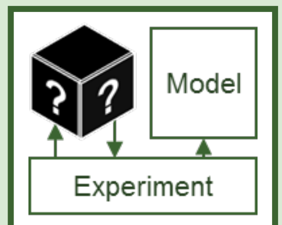


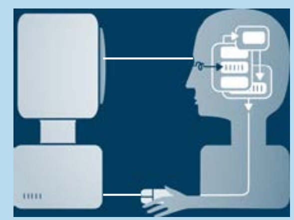
Explanation Interface

- I understand why
- I understand why not
- I know when you'll succeed
- I know when you'll fail
- I know when to trust you
- I know why you erred









Deep Explanation	Interpretable Models	Model Induction	HCI	Psychology
Learning Semantic Associations H. Sawhney (SRI Sarnoff)	**Stochastic And-Or-Graphs (AOG)** Song-Chun Zhu (UCLA)	**Local Interpretable Model-agnostic Explanations (LIME)** C. Guestrin (UW)	**Prototype Explanation Interface** T. Kulesza (OSU/MSR)	**Principles of Explanatory Machine Learning** M. Burnett (OSU)
Learning to Generate Explanations T. Darrell, P. Abeel (UCB)	**Bayesian Program Learning** J. Tenenbaum (MIT)	**Bayesian Rule Lists** C. Rudin (MIT)	**UX Design, Language Dialog, Visualization** ENGINEERING PRACTICE	**Psychological Theories of Explanation** T. Lombrozo (UCB)

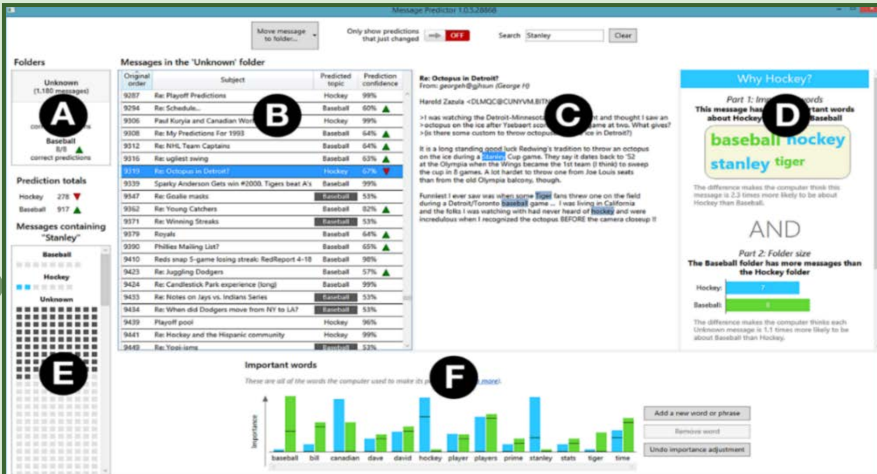
Explanation Interface – A Simple Example

Principles

Explainability
- Be Iterative
- Be Sound
- Be Complete
- Don't Overwhelm

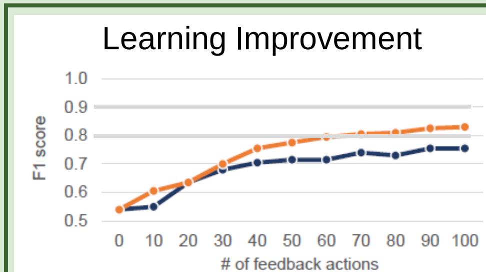
Correctability
- Be Actionable
- Always Honor User Feedback
- Incremental Changes Matter

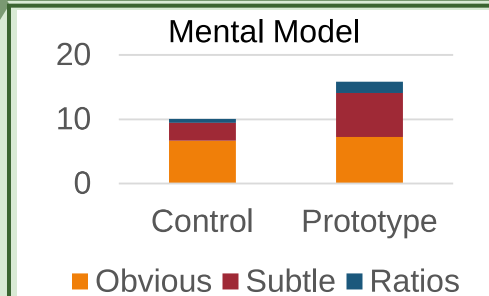
Prototype



(A) List of folders; (B) List of messages in the folder; (C) The selected message; (D) Explanation of the message's predicted folder; (E) Overview of messages; (F) Complete list of words the system used to make predictions

Results

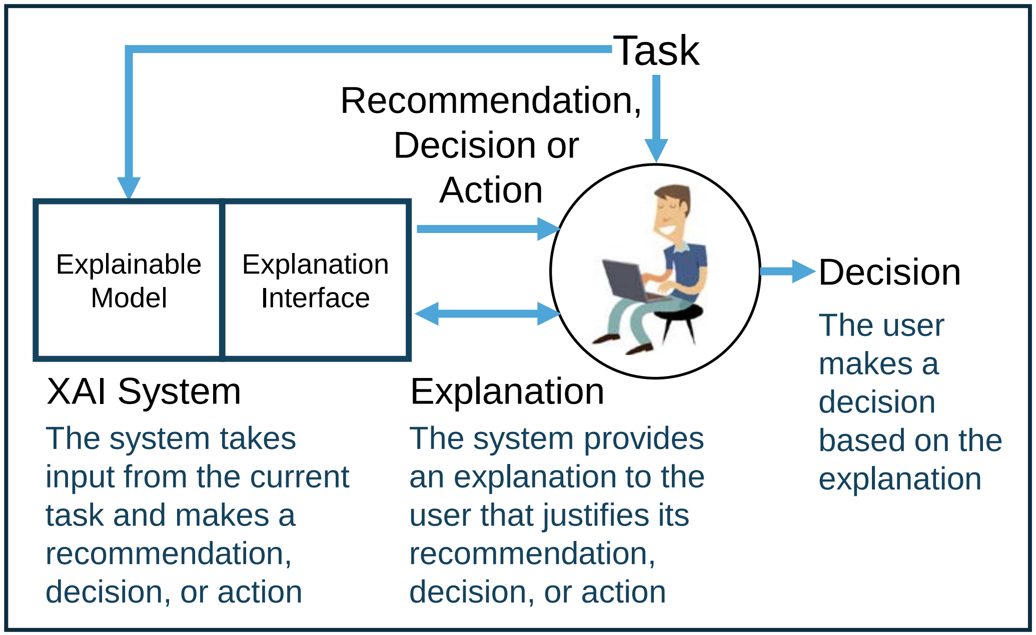




Kulesza, T., Burnett, M., Wong, W.-K., & Stumpf, S. (2015). Principles of Explanatory Debugging to Personalize Interactive Machine Learning. *IUI 2015, Proceedings of the 20th International Conference on Intelligent User Interfaces* (pp. 126-137).

Explainable AI – Measuring Evaluation Effectiveness

Explanation Framework



Measure of Explanation Effectiveness

User Satisfaction

- Clarity of the explanation (user rating)
- Utility of the explanation (user rating)

Mental Model

- Understanding individual decisions
- Understanding the overall model
- Strength/weakness assessment
- 'What will it do' prediction
- 'How do I intervene' prediction

Task Performance

- Does the explanation improve the user's decision, task performance?
- Artificial decision tasks introduced to diagnose the user's understanding

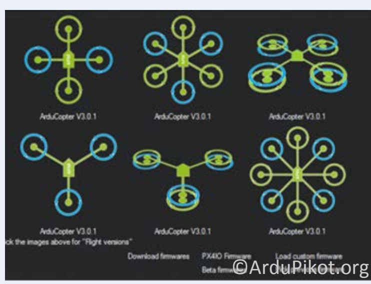
Trust Assessment

- Appropriate future use and trust

Correctablity

- Identifying errors
- Correcting errors
- Continuous training

Explainable AI – Challenge Problem Areas

	Learn a model to perform the task	Explain decisions, actions to the user	Use the explanation to perform a task	
Data Analytics Classification Learning Task	 Multimedia Data	Explainable Model → Explanation Interface	Recommend / Explanation 	An analyst is looking for items of interest in massive multimedia data sets
	Classifies items of interest in large data set	Explains why/why not for recommended items	Analyst decides which items to report, pursue	
Autonomy Reinforcement Learning Task	 ArduPilot & SITL Simulation	Explainable Model → Explanation Interface	Actions / Explanation 	An operator is directing autonomous systems to accomplish a series of missions
	Learns decision policies for simulated missions	Explains behavior in an after-action review	Operator decides which future tasks to delegate	

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Leading the world to 5G

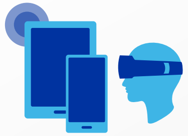
February 2016
Qualcomm Technologies, Inc.

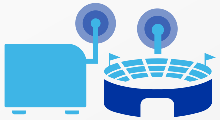
Our 5G vision: a unifying connectivity fabric

5G

Enhanced mobile broadband

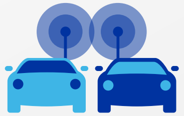
- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

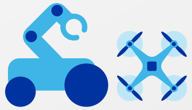

Mobile devices


Networking

Mission-critical services

- Ultra-low latency
- High reliability
- High availability
- Strong security

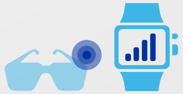

Automotive


Robotics

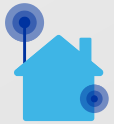
Health

Massive Internet of Things

- Low cost
- Ultra-low energy
- Deep coverage
- High density

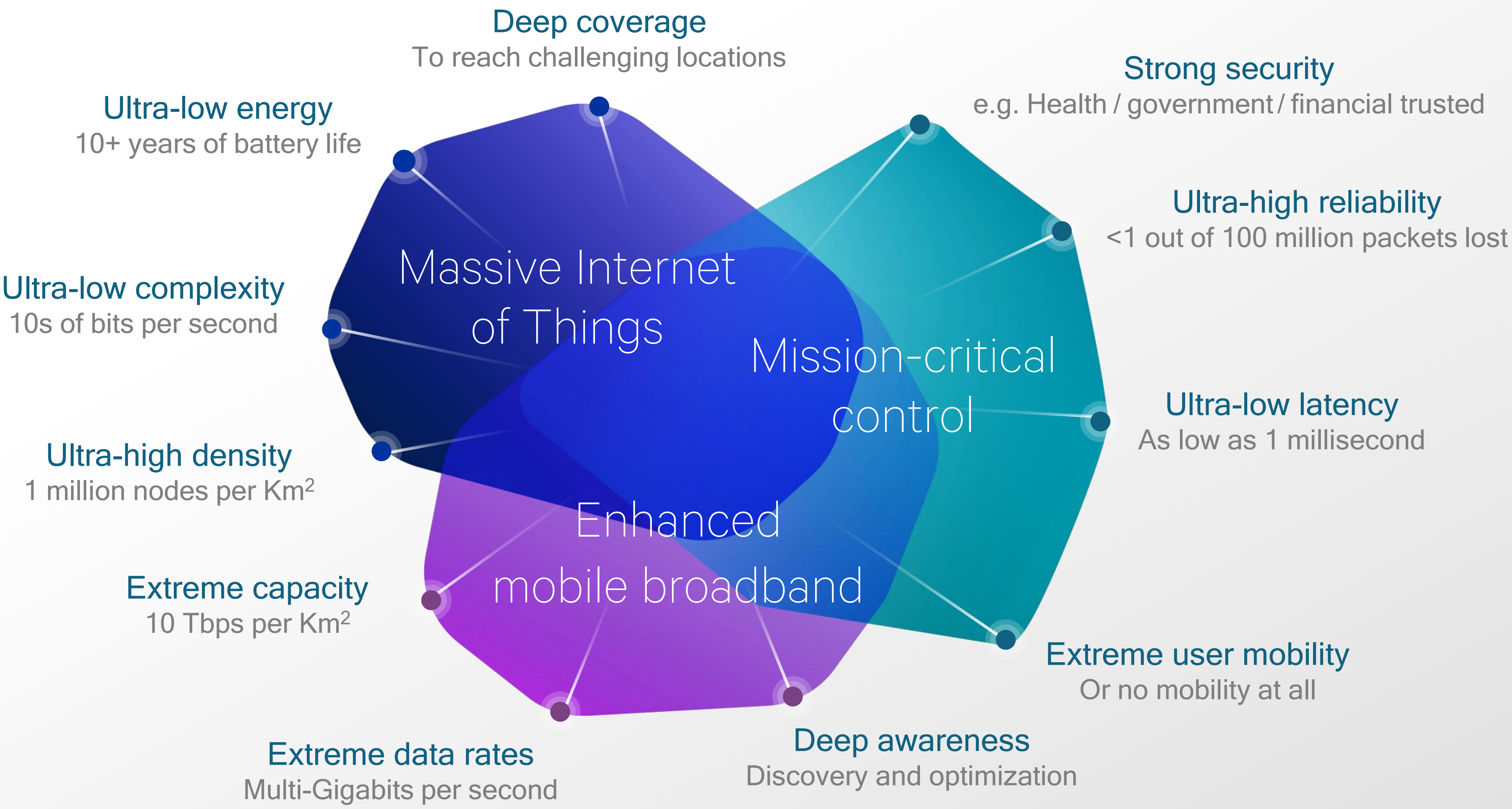

Wearables


Smart cities


Smart homes

Unified design for all spectrum types and bands from below 1GHz to mmWave

Scalable to an extreme variation of requirements



Based on target requirements for the envisioned 5G use cases

Enhancing mobile broadband

Ushering in the next era of immersive experiences and hyper-connectivity


3D/UHD video telepresence


Tactile Internet


UHD video streaming


Demanding conditions, e.g. venues


Broadband ‘fiber’ to the home


Virtual reality

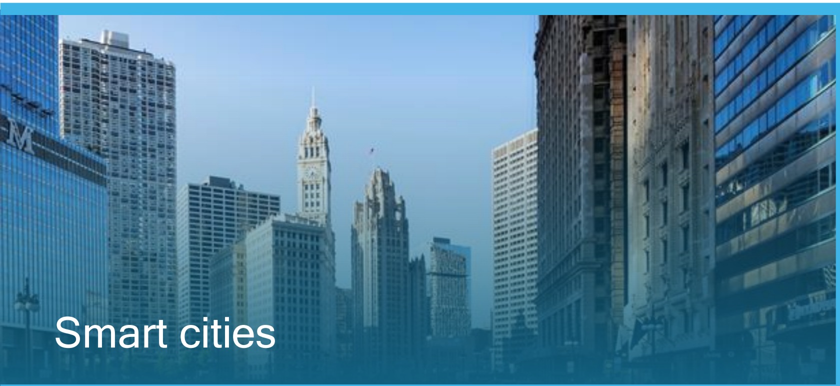
Extreme throughput
multi-gigabits per second

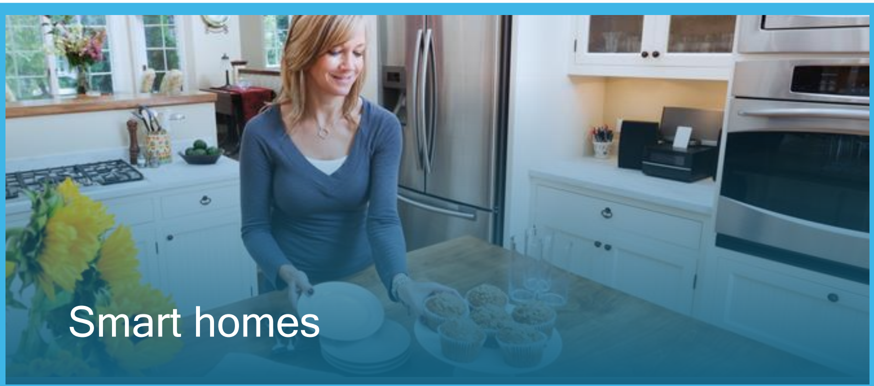
Ultra-low latency
down to 1ms e2e latency

Uniform experience
with much more capacity

Connecting the massive Internet of Things

Optimizing to connect anything, anywhere with efficient, low cost communications





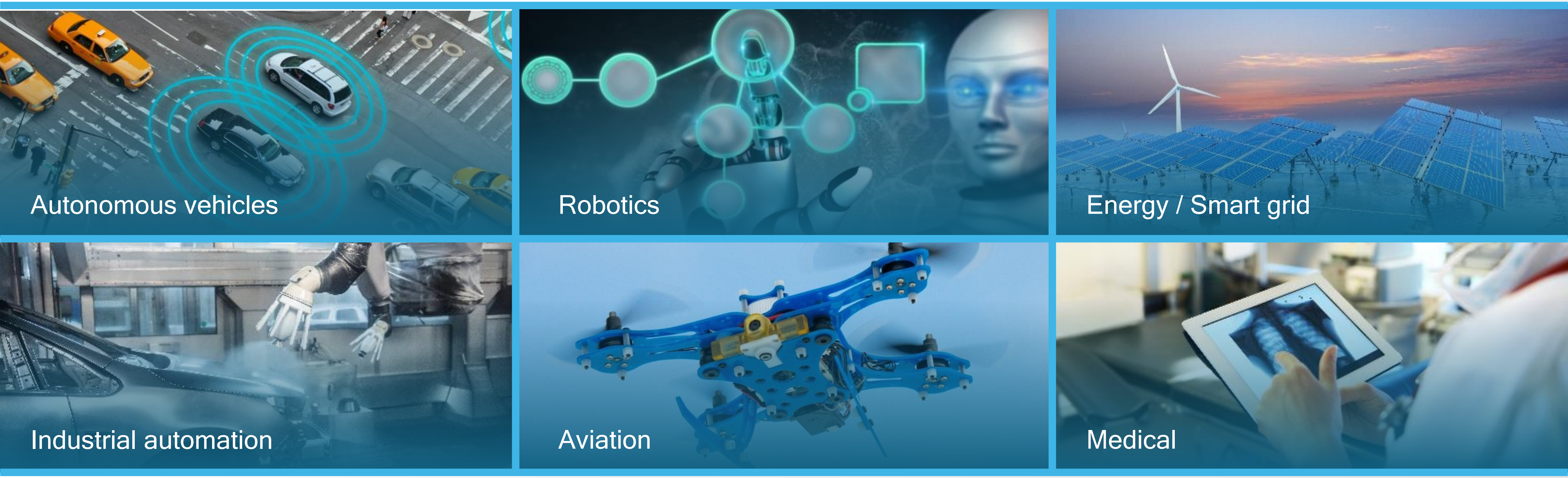
Power efficient
Multi-year battery life

Low complexity
Low device and network cost

Long range
Deep coverage

Enabling new mission-critical control services

With ultra-reliable, ultra-low latency communication links



High reliability
Extremely low loss rate

Ultra-low latency
Down to 1ms e2e latency

High availability
Multiple links for failure tolerance & mobility

A unified 5G design for all spectrum types/bands

Addressing a wide range of use cases and deployment scenarios

Licensed Spectrum
Cleared spectrum
EXCLUSIVE USE

Shared Licensed Spectrum
Complementary licensing
SHARED EXCLUSIVE USE

Unlicensed Spectrum
Multiple technologies
SHARED USE

Below 1 GHz: longer range for massive Internet of Things

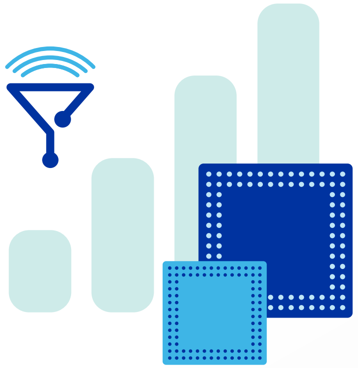
1 GHz to 6 GHz: wider bandwidths for enhanced mobile broadband and mission critical

Above 6 GHz, e.g. mmWave: extreme bandwidths, shorter range for extreme mobile broadband

From wide area macro to local hotspot deployments
Also support diverse network topologies (e.g. D2D, mesh)

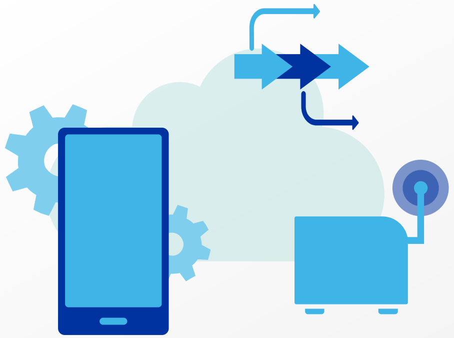
Qualcomm, leading the world to 5G

Investing in 5G for many years—building upon our leadership foundation



Wireless/OFDM technology and chipset leadership

Pioneering 5G technologies to meet extreme requirements



End-to-end system approach with advanced prototypes

Driving 5G from standardization to commercialization

Leading global network experience and scale

Providing the experience and scale that 5G demands

Pioneering 5G technologies today with LTE

We are driving 4G and 5G in parallel to their fullest potential

Advanced MIMO
Unlicensed spectrum
256QAM
Enhanced CA
FeICIC
Internet of Things
Carrier aggregation
FDD-TDD CA
Massive/FD-MIMO
CoMP
Device-to-device
Shared broadcast
SON+
Dual connectivity
V2X
Low latency

5G

Rel-15 and beyond

Further backwards-compatible 4G enhancements

Rel-10/11/12

LTE Advanced

Rel-13 and beyond

LTE Advanced Pro

2015

2020+

Note: Estimated commercial dates. Not all features commercialized at the same time

Driving new LTE technologies to commercialization

Pushing LTE towards 5G with our unique end-to-end system approach

End-to-end prototype platforms

First LTE Unlicensed live demo at MWC 2014

Standards and research leadership

Pioneered LTE Unlicensed work in 3GPP

Industry-first trials with network operators

First LAA over-the-air trial in November 2015

Industry-first chipsets*

First modem and small cell solution to support LAA

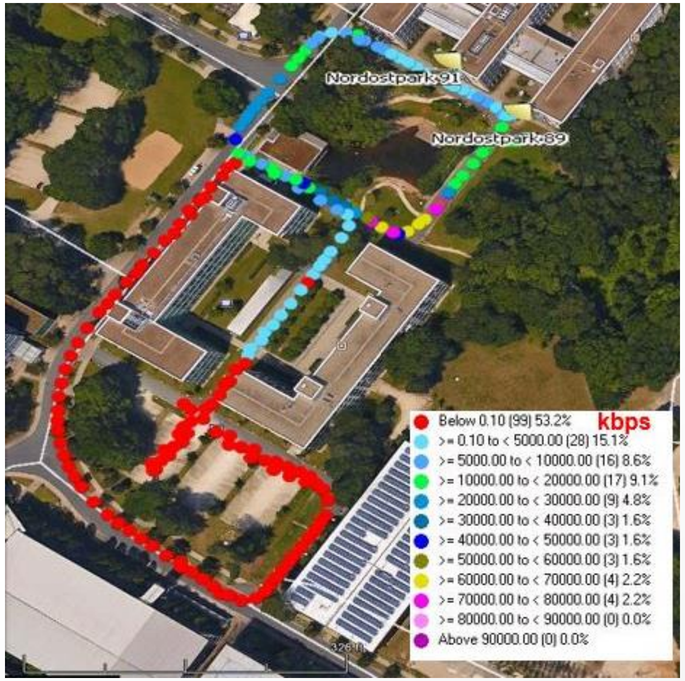
Example: Driving LTE Unlicensed to commercialization

* Chipsets are products of Qualcomm Technologies, Inc.; firsts with respect to public announcement of a commercial LTE modem chipset

World's first over-the-air LAA trial during November 2015

Joint effort by Qualcomm Technologies with Deutsche Telekom AG

LWA (Wi-Fi) test route*



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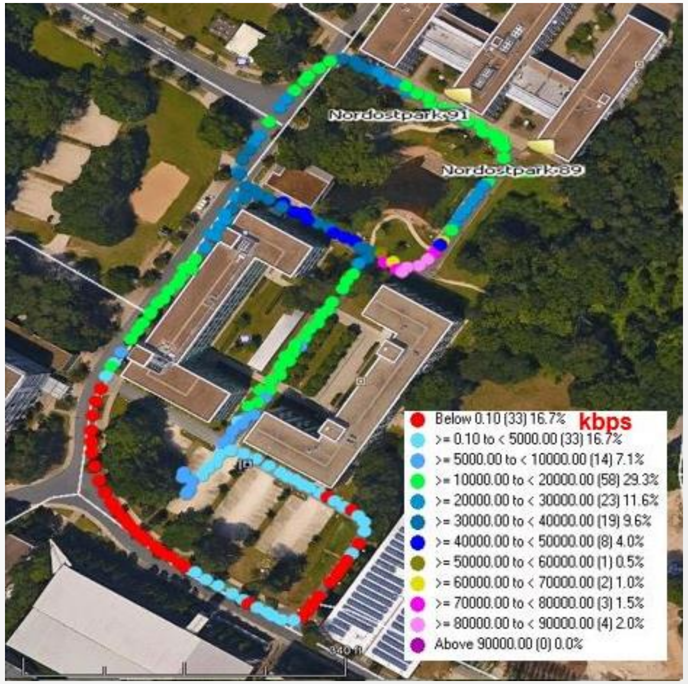
LAA test route*



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Coverage^ in unlicensed

Mbps	Wi-Fi	LAA
		x 2.5
>10	24% of route	60% of route
		x 1.8
>1	39% of route	71% of route
		x 1.7
>0	47% of route	82% of route

Wide range of indoor and outdoor test cases

Demonstrated coverage and capacity benefits of LAA

Demonstrated fair co-existence with Wi-Fi

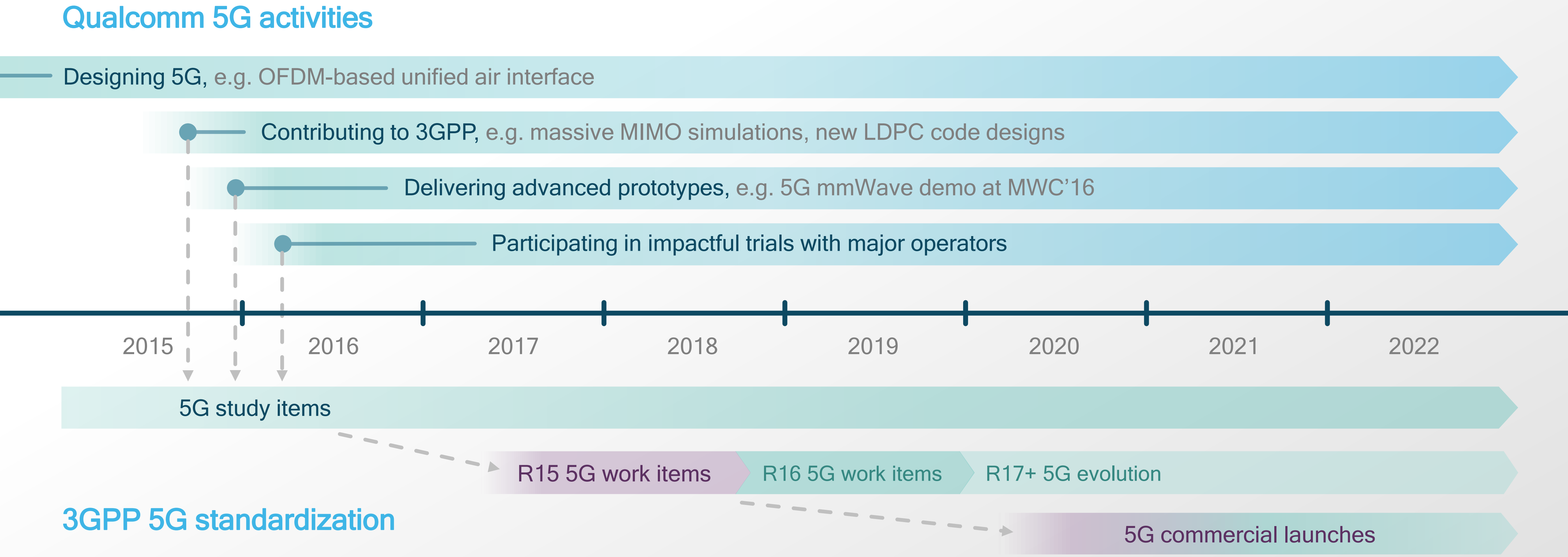
* Single small cell, LAA based on 3GPP release 13; LWA using 802.11ac; LTE on 10 MHz channel in 2600 MHz licensed spectrum with 4W transmit power; the following conditions are identical for LAA and Wi-Fi: 2x2 downlink MIMO, same 20 MHz channel in 5 GHz unlicensed spectrum with 1W transmit power, terminal transmit power 0.2W, mobility speed 6-8 mph; ^ Based on geo-binned measurements over test route

Multi-mode/multi-connectivity essential to 5G success

Simultaneous connectivity across 5G, 4G and Wi-Fi

Leading the world to 5G

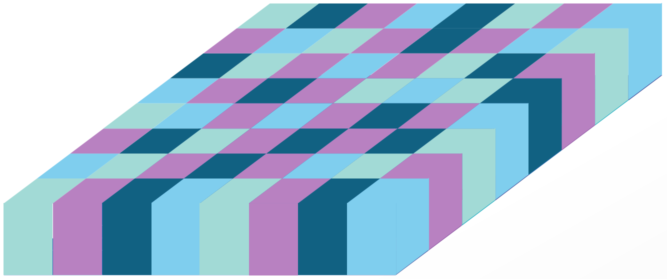
From standardization to commercialization



Note: Estimated commercial dates;

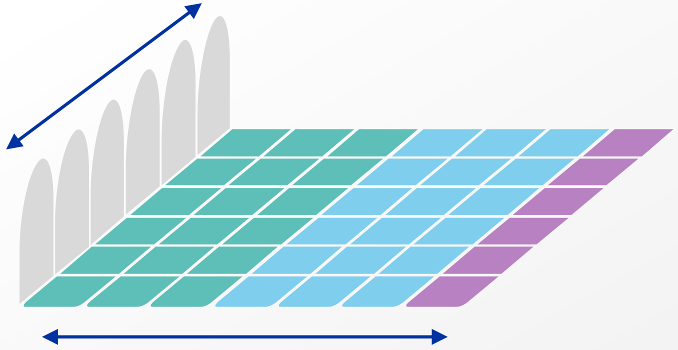
Designing a unified, more capable 5G air interface

Building on our strong OFDM/wireless foundation



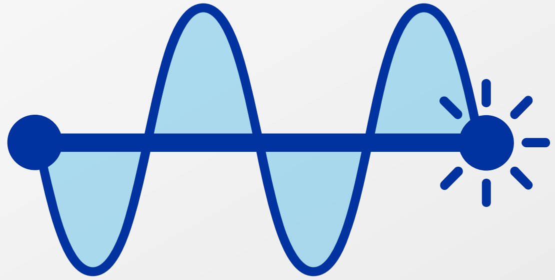
Optimized OFDM-based waveforms

OFDM adapted to extremes



A common, flexible framework

Designed for forward compatibility

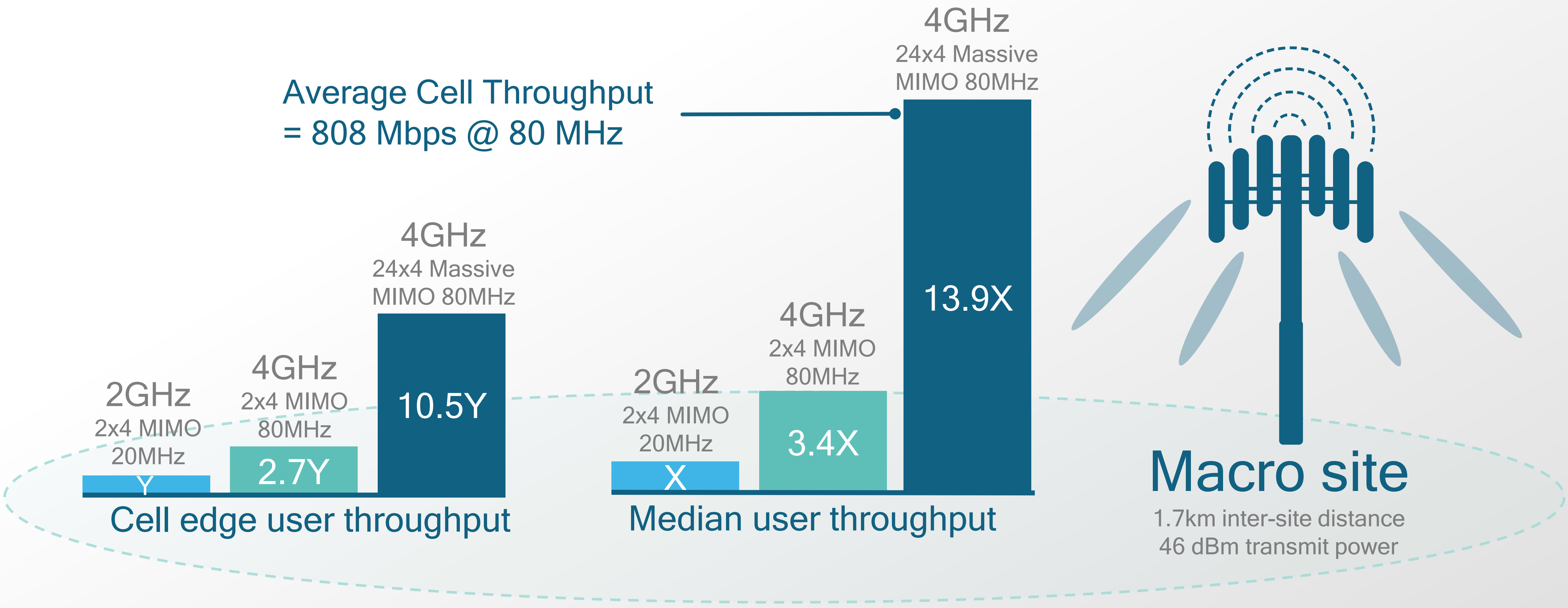


Advanced wireless technologies

Such as massive MIMO, mmWave

Massive MIMO at 4 GHz allows reuse of existing sites

Leverage higher spectrum band using same sites and same transmit power



Source: Qualcomm Technologies, Inc. simulations; Macro-cell with 1.7km inter-site distance, 10 users per cell, 46 dBm Tx power at base station, 20MHz@2GHz and 80MHz@4GHz BW TDD, 2.4x Massive MIMO

Realizing the mmWave opportunity for mobile broadband

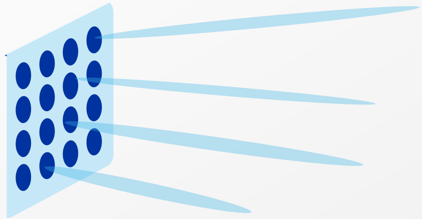
The extreme mobile broadband opportunity

- Large bandwidths, e.g. 100s of MHz
- Multi-Gpbs data rates
- Flexible deployments (integrated access/backhaul)
- High capacity with dense spatial reuse

The challenge–'mobilizing' mmWave

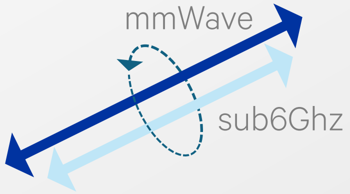
- Robustness due to high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G Solutions



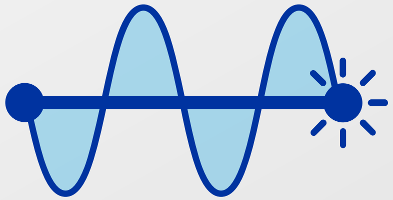
Intelligent directional beam forming & beam tracking

Increase coverage & provide continuous connectivity



Tight interworking with sub 6 GHz

Increase robustness and faster system acquisition



Optimized mmWave design for mobile

To meet cost, power & thermal constraints

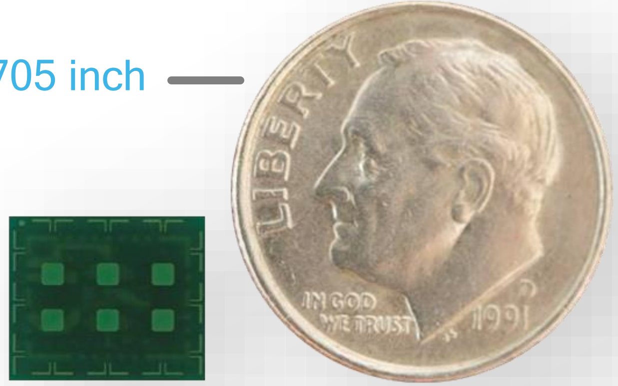
Making mmWave a reality for mobile

Qualcomm is driving 5G mmWave

60 GHz chipset commercial today for mobile devices

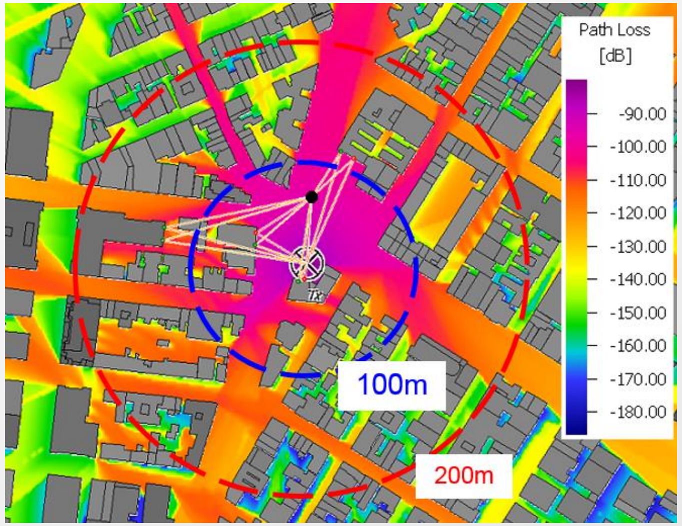
0.705 inch

0.28 inch



Qualcomm® VIVE™ 802.11ad technology with a 32-antenna array element

Developing robust 5G mmWave for extreme mobile broadband



Manhattan 3D map

Results from ray-tracing^

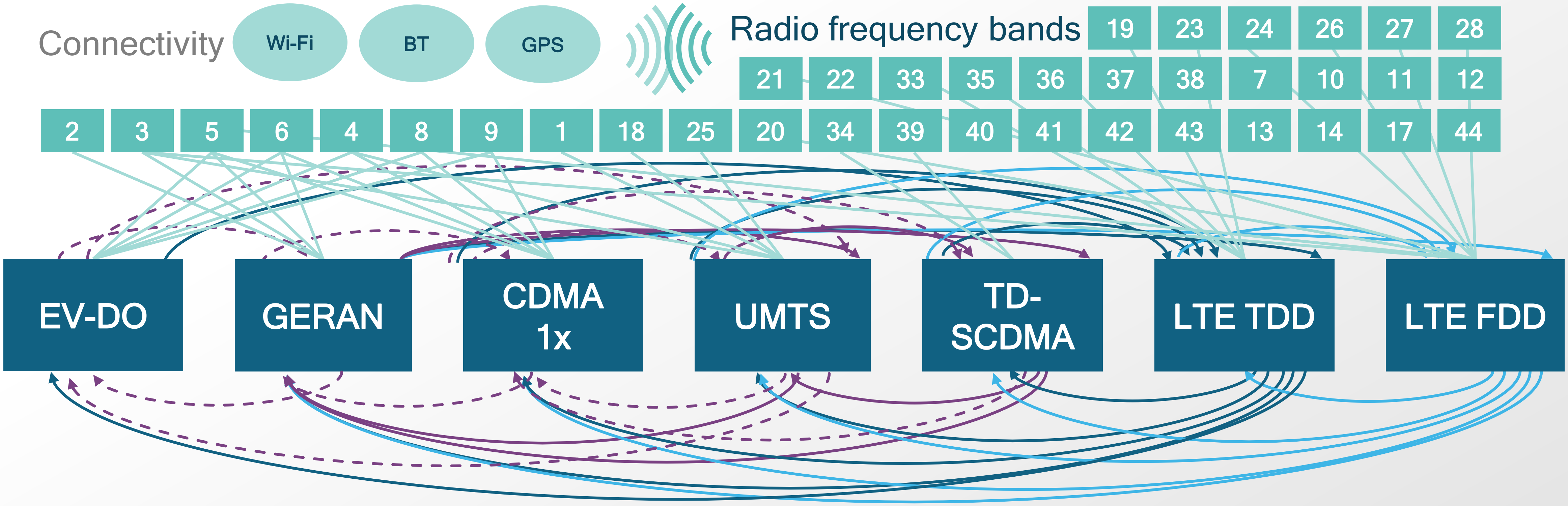
28 GHz outdoor example with ~150m dense urban LOS and NLOS coverage using directional beamforming^

Qualcomm VIVE is a product of Qualcomm Atheros, Inc.;

^ Based on Qualcomm Technologies Inc. simulations

Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving



Handover combinations (hypothetical examples) LTE 2G/3G

Source: Qualcomm Technologies Inc.

2012 LTE Multimode | Today—LTE evolution | Tomorrow—5G and LTE evolution

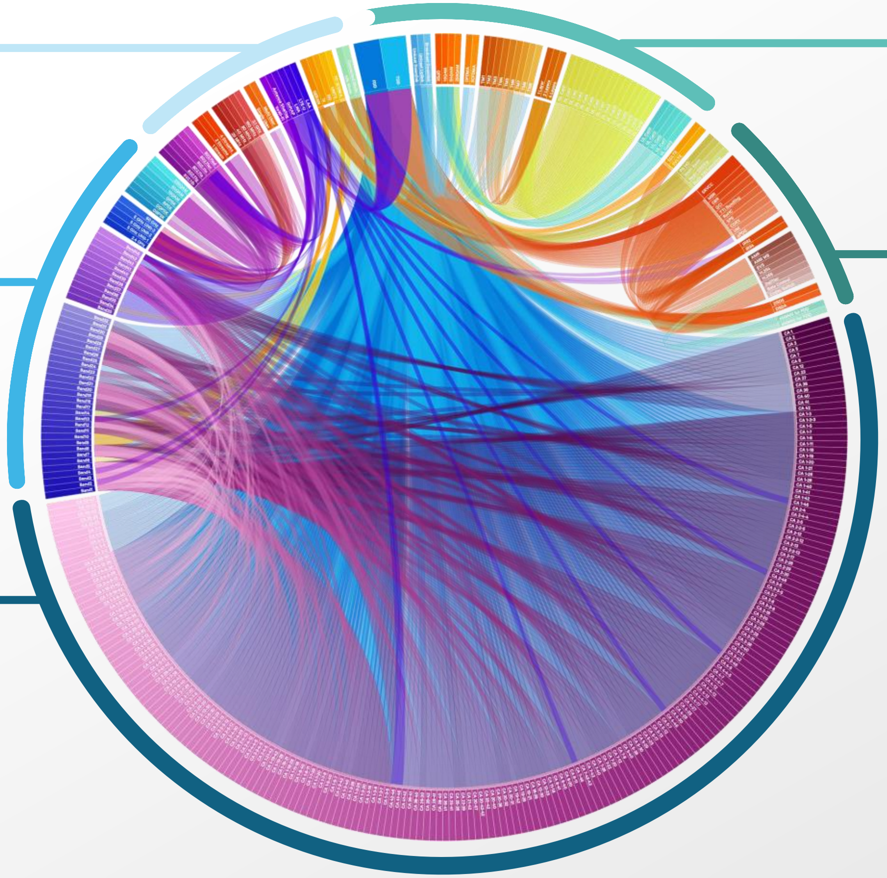
Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Wi-Fi, 3G, 2G technologies

50+ spectrum bands 450 MHz-5.8 GHz (licensed and unlicensed)

~200 Carrier Aggregation combinations



4G LTE OFDM-based waveforms, transmission modes, and UE categories

New LTE services, e.g. LTE Broadcast, VoLTE

2000+

modem features to-date and counting

Source: Qualcomm Technologies Inc.

2012 LTE Multimode | Today–LTE evolution | Tomorrow–5G and LTE evolution

Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Many more spectrum bands / types

From below 1 GHz to mmWave

Licensed, shared and unlicensed

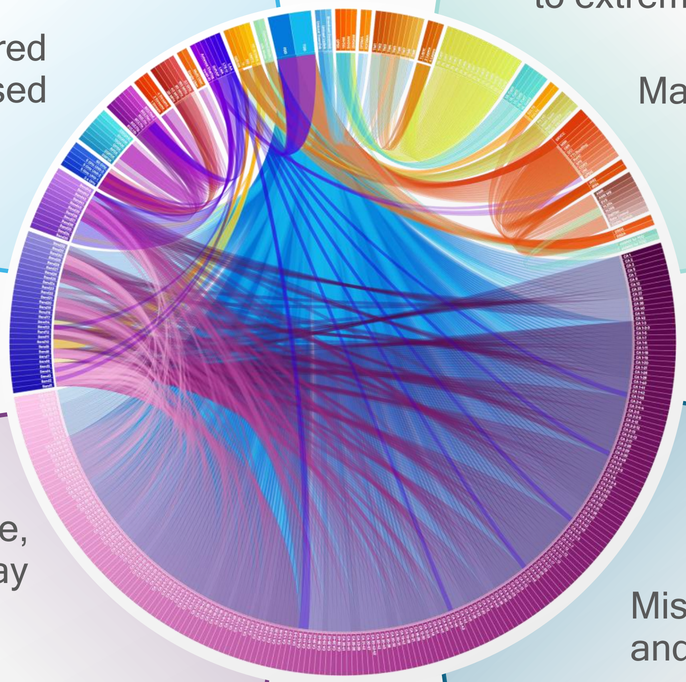
FDD, TDD, half duplex

OFDM adapted to extremes

Massive MIMO

Robust mmWave

Advanced wireless technologies



More diverse deployment scenarios

Device-to-device, mesh, relay

Wide area to hotspots

Wideband to narrowband

Mission-critical and nominal traffic

High to no mobility

A much wider variation of use cases

Source: Qualcomm Technologies Inc.

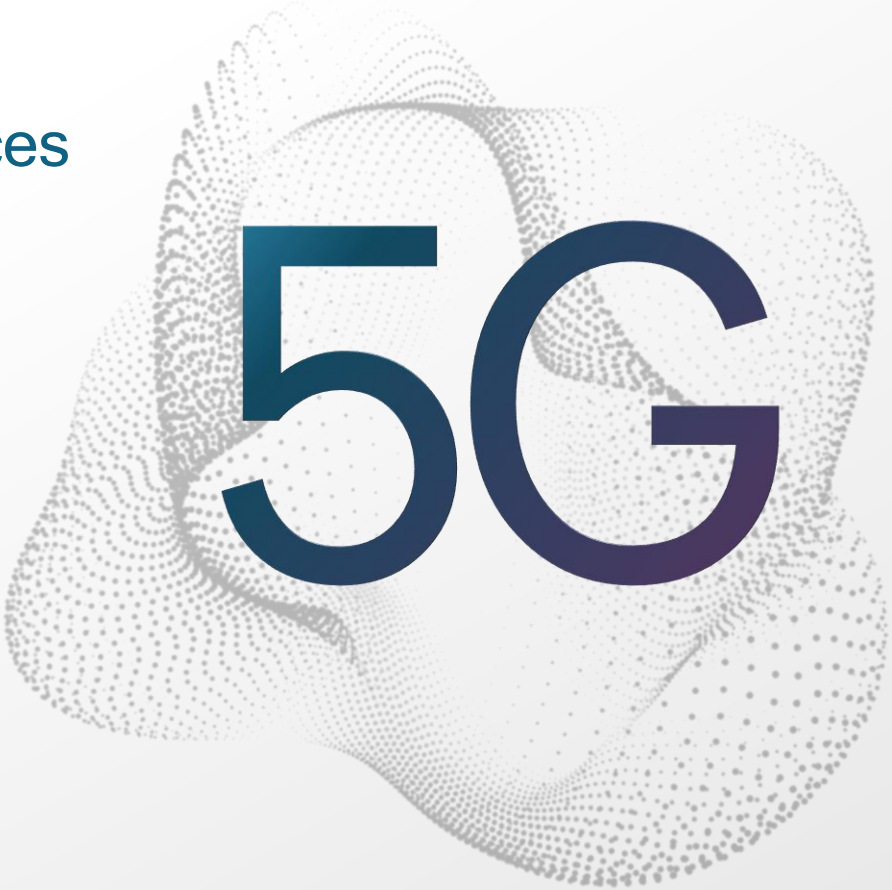
2012 LTE Multimode | Today–LTE evolution | Tomorrow—5G and LTE evolution

Leading the world to 5G

A unifying connectivity fabric for the next decade and beyond

Connecting new industries and devices

Empowering new user experiences



Enabling new services

Delivering new levels of efficiency

Questions? - Connect with Us

www.qualcomm.com/wireless

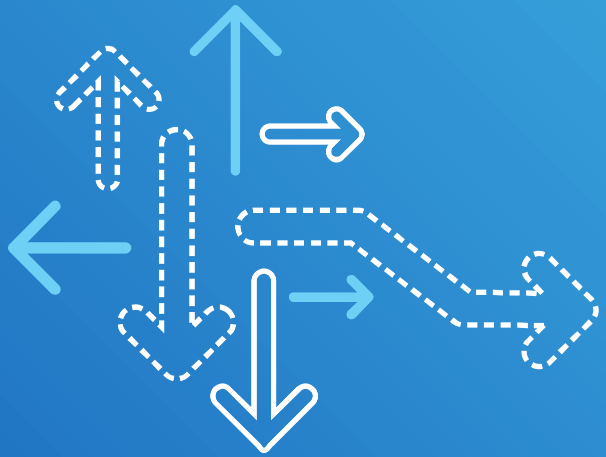
BLOG

www.qualcomm.com/news/onq

@Qualcomm_tech

http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution



Thank you

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IoT and 5G: spectrum and networking

Elias Tragos

Research associate

Telecommunications and Networks Laboratory,

Institute of Computer Science,

Foundation for Research and Technology, Hellas.

IoT challenges

- Nodes
  - low processing capacity
  - low memory capacity
  - low storage capacity
  - power constrained
  - self configuration
  - diverse capabilities

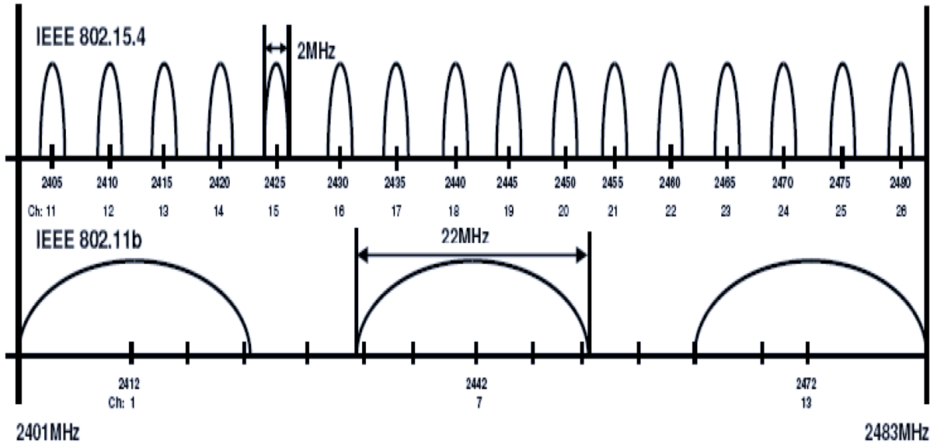
IoT challenges

- Network
  - Power consumption by network operations
  - Robustness/Redundancy
    - Node fault tolerance
    - Communication fault tolerance
  - Security/privacy
  - Scalability
  - Diverse traffic demands (!)
    - High throughput, high delay
    - Emergency (low throughput, low delay)
    - Bursty
  - Big data
  - Interference
  - deployment cost

IoT challenges

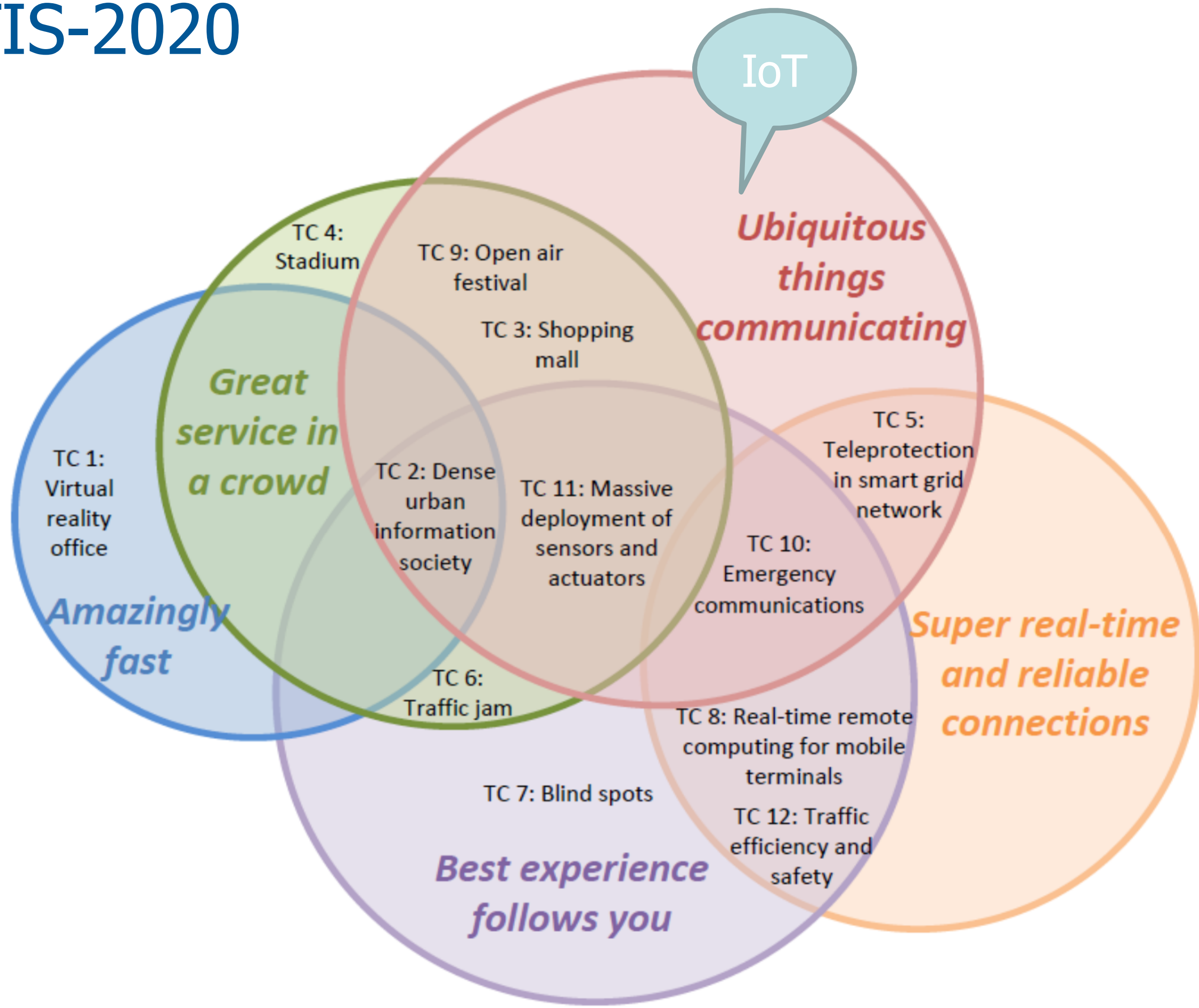
Spectrum issues

- Unlicensed bands are overcrowded
  - Wifi
  - Bluetooth
  - Wireless microphones
  - Microwave ovens
- Unlicensed bands cannot support large scale WSNs
  - communicating devices with little or no human intervention
  - M2M/IoT
  - devices respond to events
    - congestion
- Licensed bands cost



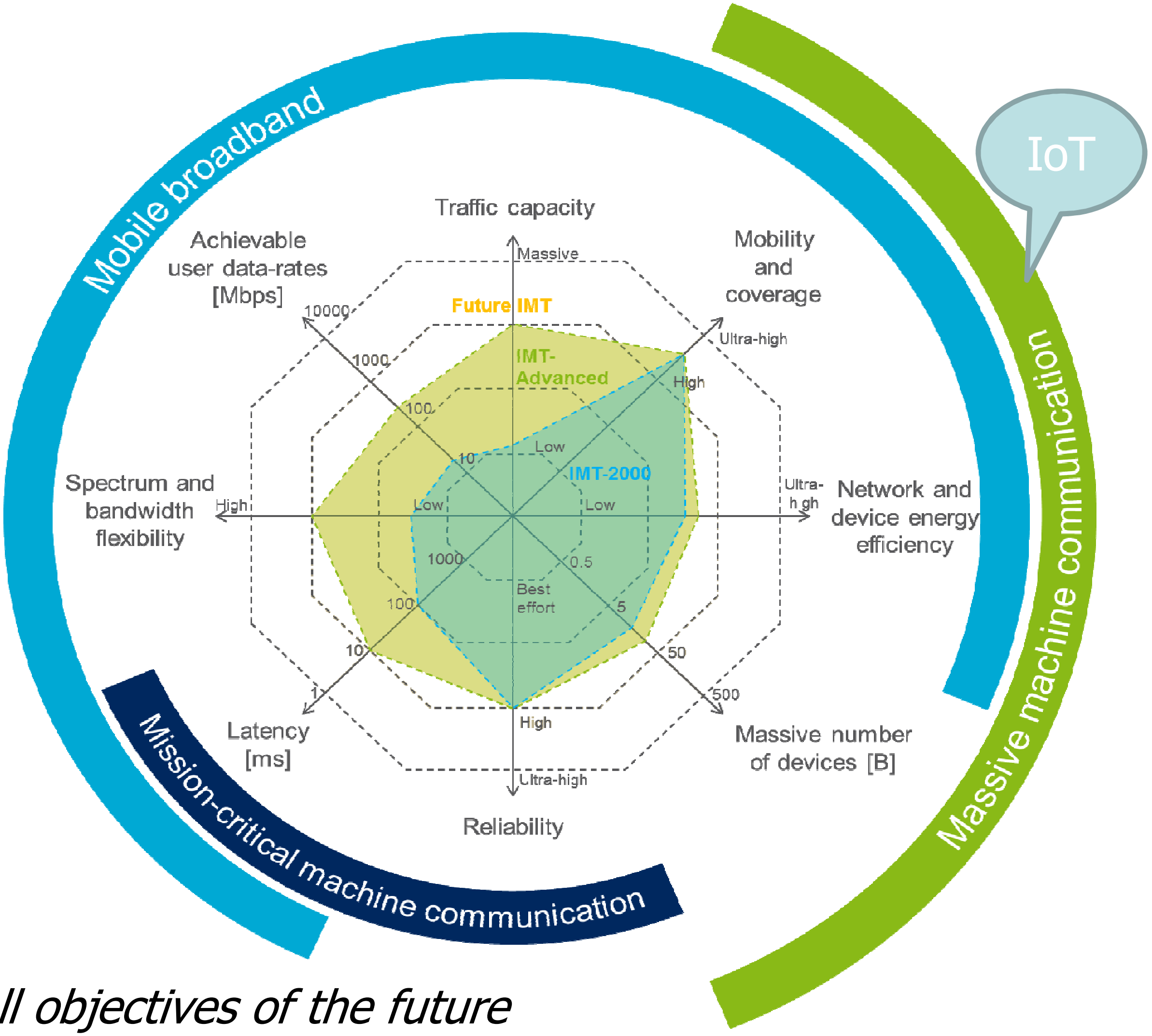
5G scenarios and IoT

✦ METIS-2020



5G scenarios and IoT

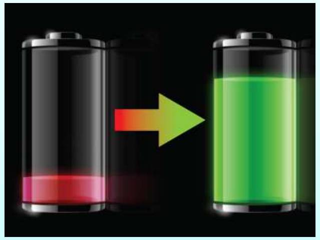
✦ *IMT Vision*



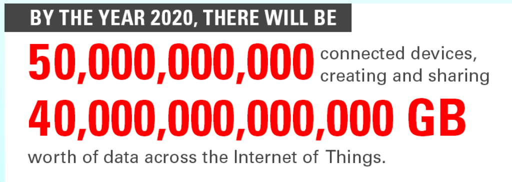
"Framework and overall objectives of the future development of IMT for 2020 and beyond" feb14

IoT requirements for 5G

Energy efficiency

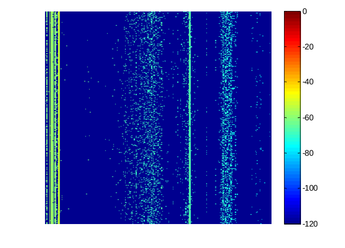


Scalability



Dense cells

Spectrum efficiency

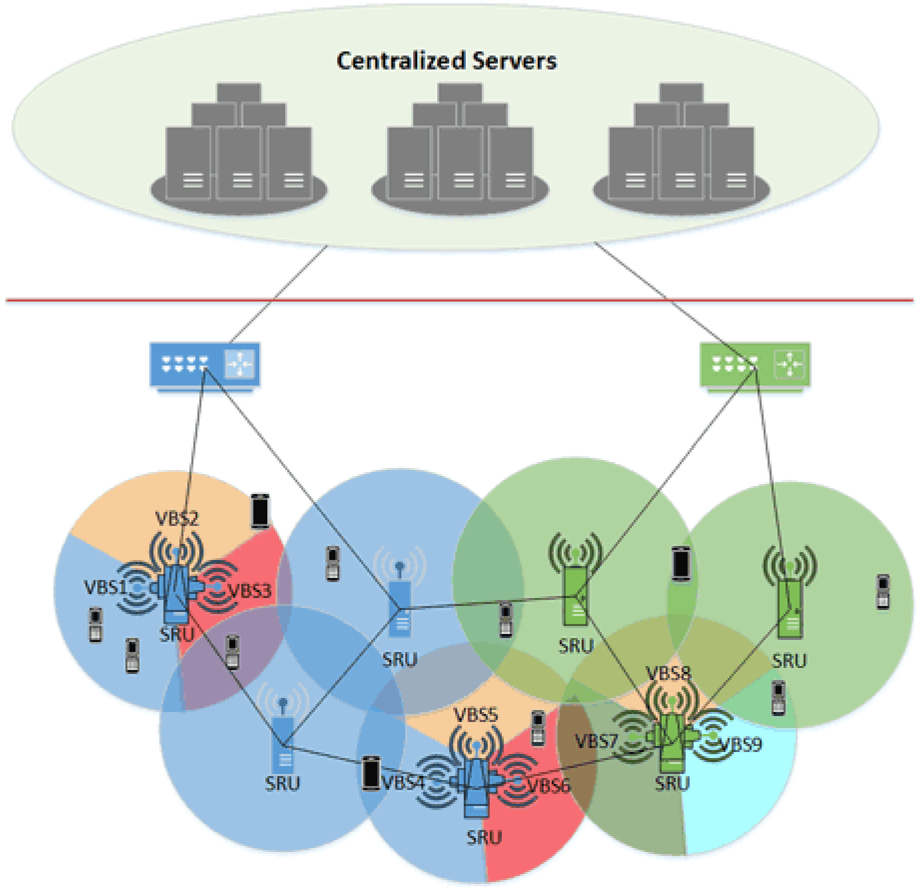


Cost efficiency

Constrained devices

5G solution for IoT

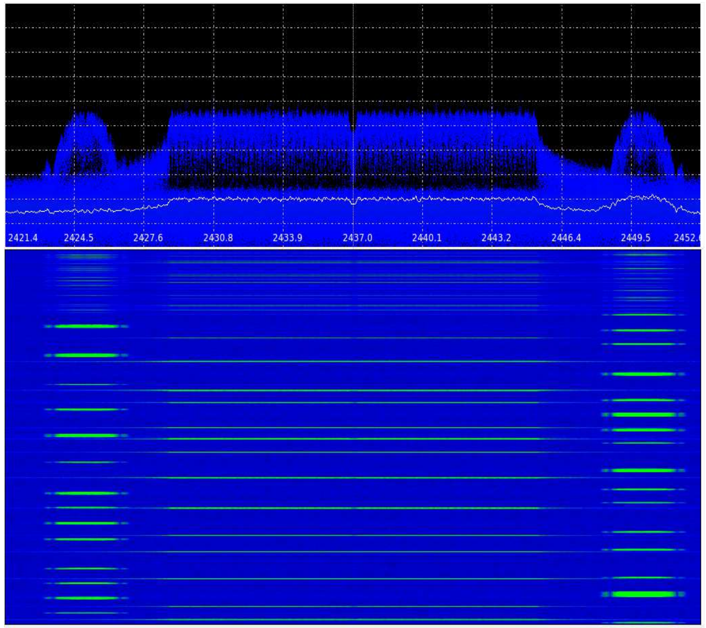
- SDR-based Cloud-RAN architecture
  - Energy efficient
  - Reprogrammable BSs
    - SDN
    - NFV
    - Multiple access
  - Hybrid network mgmt
  - Optimal resource allocation
    - Pool of BSs
    - Load balancing/offloading
    - Service prioritization
  - Cost efficient

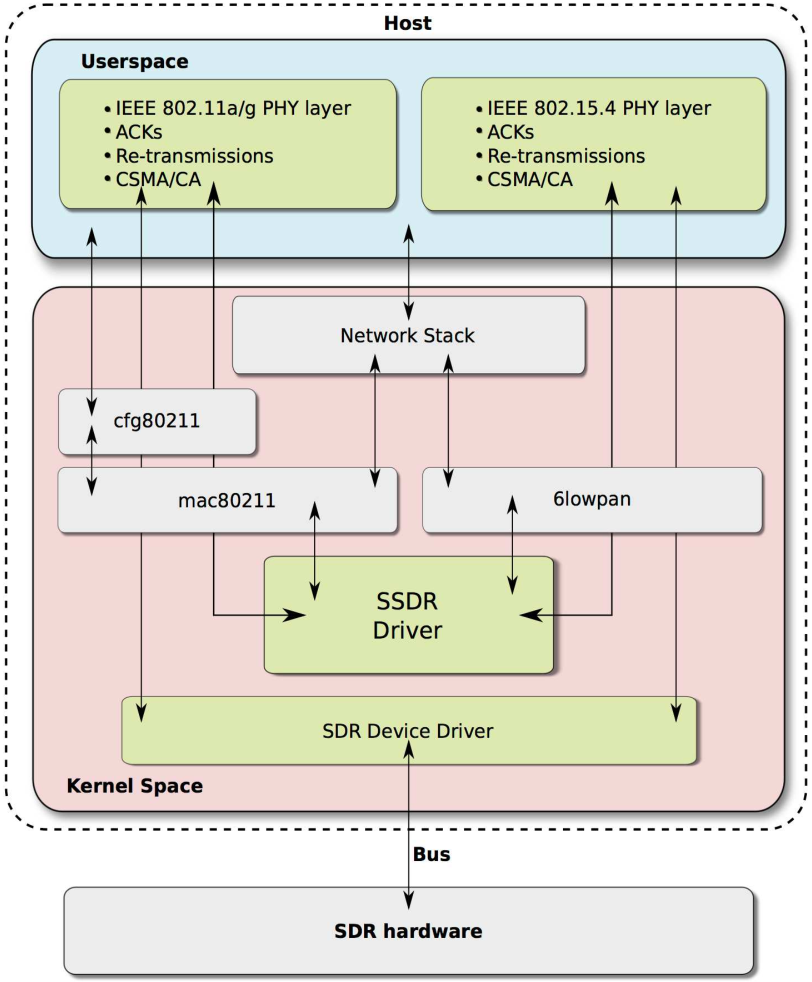


*ercim news 101

5G solution for IoT

- SDR-based Base Stations
  - 1 network interface card
  - Virtual interfaces
  - Multiple technologies
    - 802.11g
    - 802.15.4/6LowPAN





The research leading to these results has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2013) under grant agreement no 609094.

www.ict-rerum.eu

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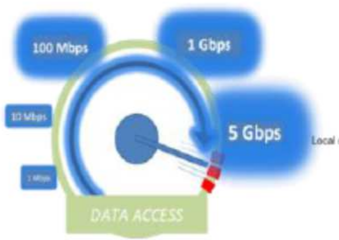
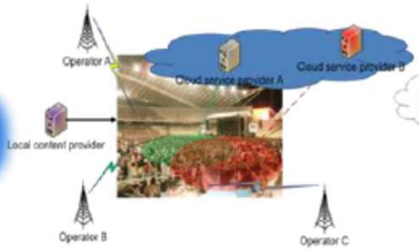
5G scenarios and IoT

✦ METIS-2020

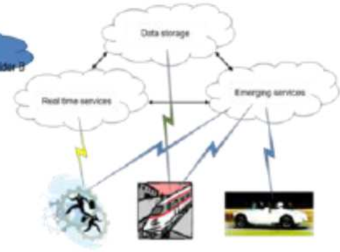
IoT



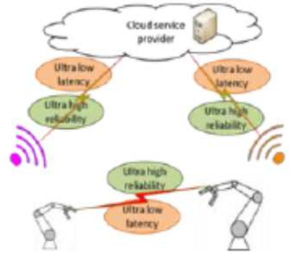
Amazingly fast



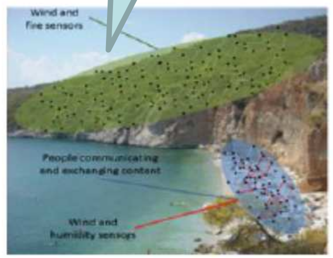
Great service in a crowd



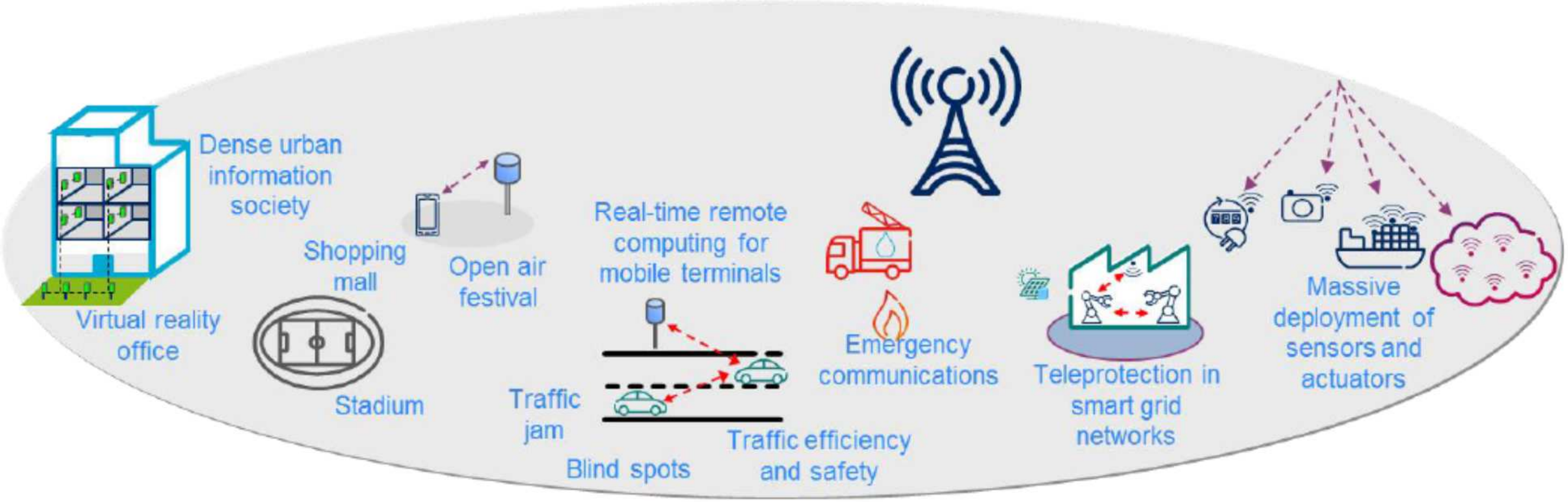
Best experience follows you



Super real-time and reliable connections



Ubiquitous things communicating



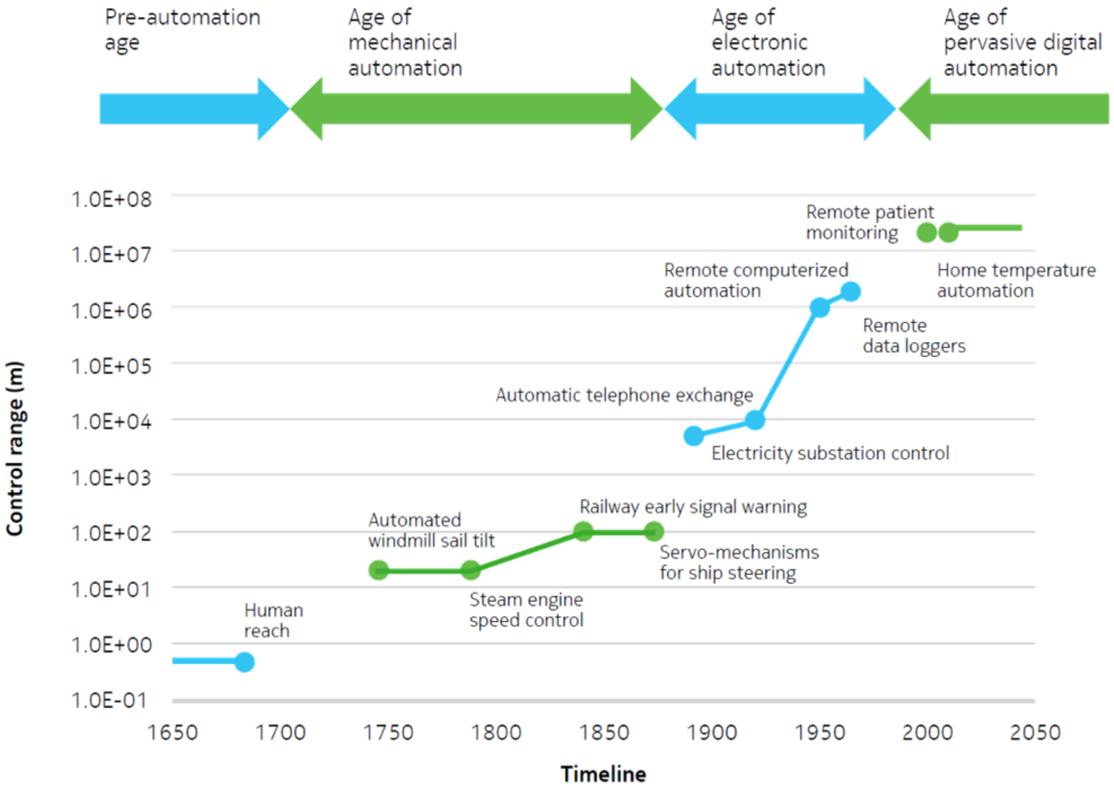
Future of IoT

The Transformation to Pervasive Digital Automation

Christele Bouchat

This presentation does not include mission critical communication

The Four Ages of Automation

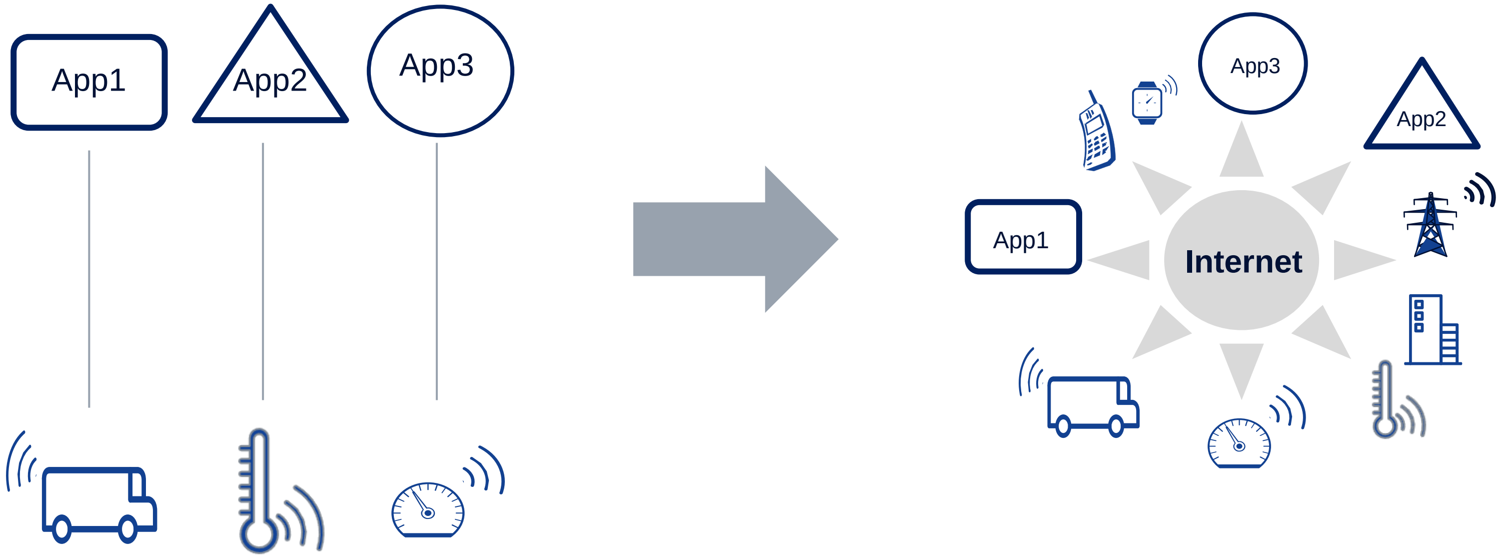


We are at the threshold of a new era in automation that dwarfs the previous eras in scale, speed, reach, diversity with major impact to how we live

NOKIA Bell Labs

The Transformation from Point Solutions to IoT

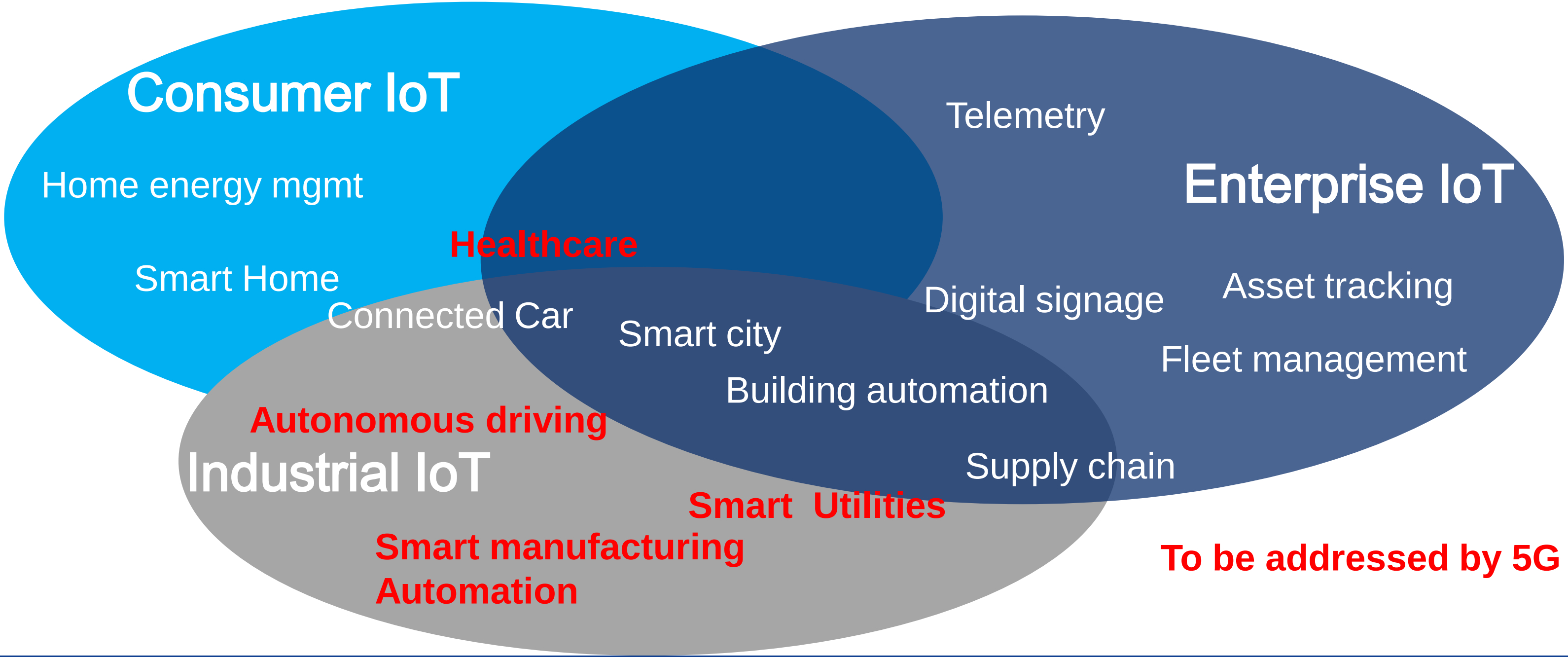
From the Intranet of Things to the Internet of Things



A shift from point to point monitoring and control solutions to a connection to the Internet is driving the large scale digitization of things

Segmentation in to Verticals

Consumer, Enterprise and Industrial IoT



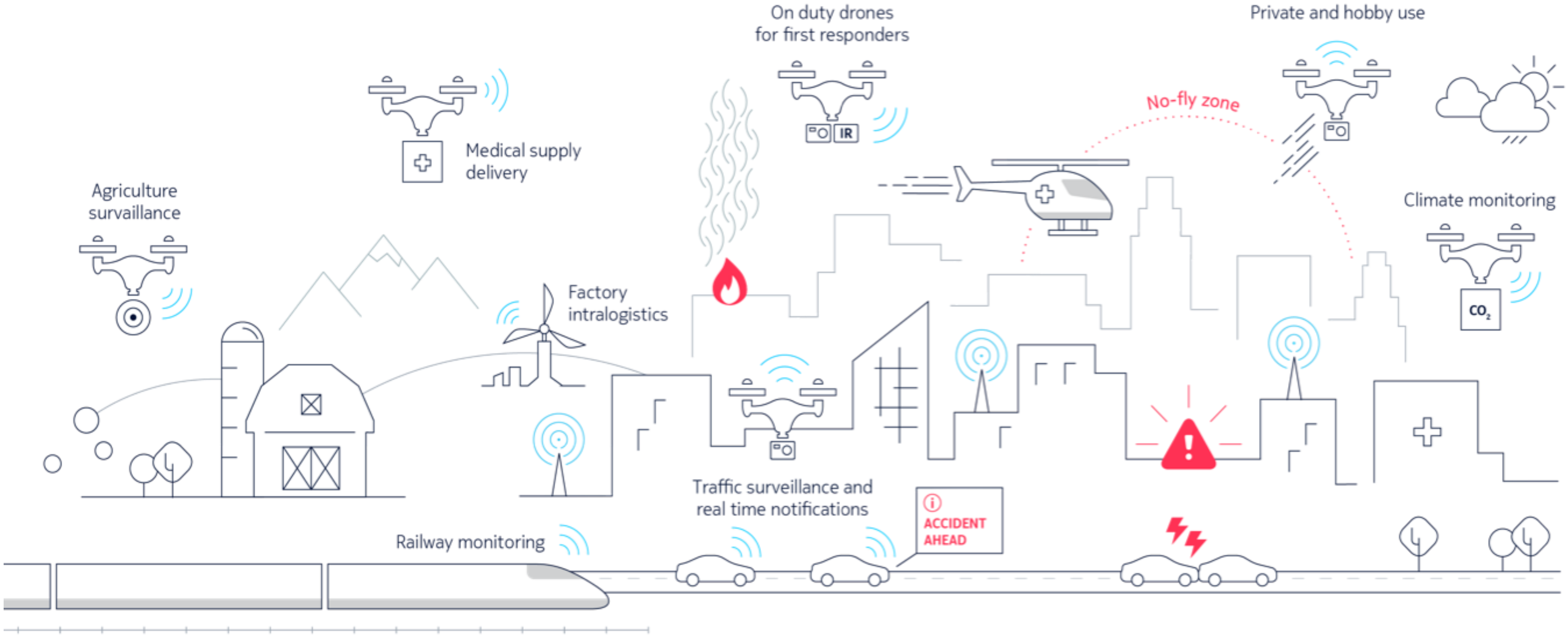
Significant variation in market penetration and growth across verticals with Industrial IoT in infancy & Consumer and Enterprise IoT accelerating

NOKIA Bell Labs

Unmanned Aerial Vehicles for Smart Solutions

With LTE: not very efficient because of interferences

5G to improve the quality of the link



NOKIA Bell Labs

Latency and Reliability Requirements

Reliability: high / low

eHealth
(body sensors)
- Relaxed Latency needs
- High reliability requirements
- Specialty: Long battery lifetime required

Smart Grid
- Moderate to high latency and reliability requirements
- Specialty: Large distances to be covered

Automotive
- E2E latency < 5-10 ms [1]
- Reliability up to BLER 10^{-6}
- Specialty: Mobility
- Positioning accuracy 0.5m

Augmented Reality
- E2E latency < 10 ms to avoid cyber sickness
- Reliability requirements less tough (but need to detect failures reliably)
- Specialty: High data rates

Industry Automation
- E2E latency partially < 0.5 ms
- Reliability up to BLER 10^{-9} [2]
- Specialty: Often isolated areas

Remote robotics / surgery
- E2E latency < 1 ms due to need for haptic feedback
- Reliability up to BLER 10^{-9}

Latency: high / low

1) METIS D1.1
2) A. Frotzscher et al., Requirements and current solutions of wireless communication in industrial automation, ICC 2014

Technologies Enabling the Pervasive Digital Automation

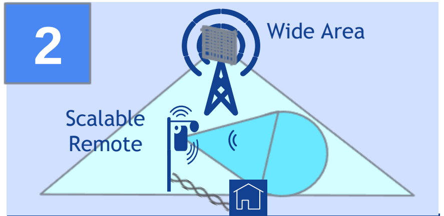
Smart Devices

1

Lost cost, energy efficient/autonomous, secure, miniaturized devices for machine connectivity

Massive Scale Connectivity

2

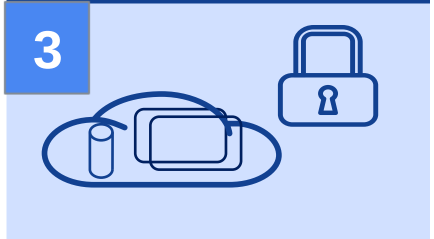


Wide area , short Range, low latency, ultra reliable, and Device to Device suitable for a broad range of applications

Secure IoT Platforms

Cloud based application enablement tools and connectivity management capabilities

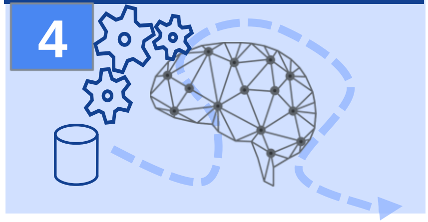
3



Intelligent IoT Analytics

Real-time predictive analytics to drive autonomous systems

4



Low cost & power for massive machine type communication
3GPP LTE-M and NB-IoT

> 10 Years Battery life

Longer sleeping cycles

Less signaling for wakeup

Power save mode

Low Cost Device

Narrowband transmission

Reduced transmit power

Limited downlink transmission modes

UE processing relaxations

4 x coverage
compared to current LTE

Repetition and power spectral density boosts

+15~20 dB coverage

Standardized in 2016

In 3GPP LTE

Need to be deployed

And learned from it

IoT to be included

In latter phase of 5G

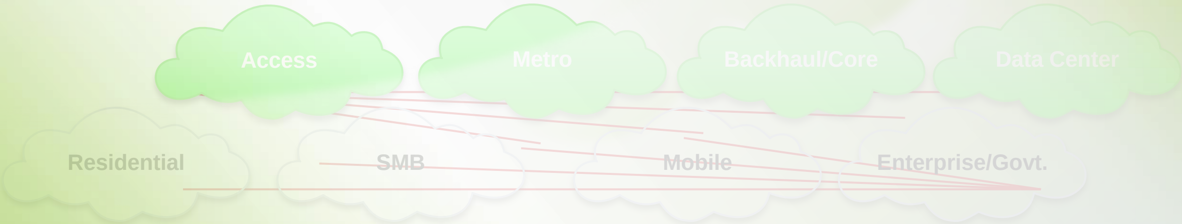
Expanding Cellular Connectivity to new IoT Application categories

NOKIA Bell Labs

broadband forum

Open Broadband

[Click here for more info]



Open Broadband

Open Broadband is collaborative space for the integration and testing of new open source, standards-based and vendor provided implementations

Collaboration between Open Broadband and other industry projects

- OB-I is the infrastructure platform that will provide physical lab resources to facilitate integration, testing, etc.
  - With other organizations such as ETSI NFV ISG, ONF, IETF, etc.
  - With open source projects (OPNFV, Open-O, OCP, ONOS, OpenCORD, Open Daylight, OpenStack, etc.) will provide implementations into the Open Broadband
  - With BBF projects such as CloudCO, BBF service modeling, the virtualized broadband network, 5G services, IoT,…
- Enables testing of integration for commercial deployments and vendor provided solutions

Aalto University

Industrial Internet, an IoT case for 5G

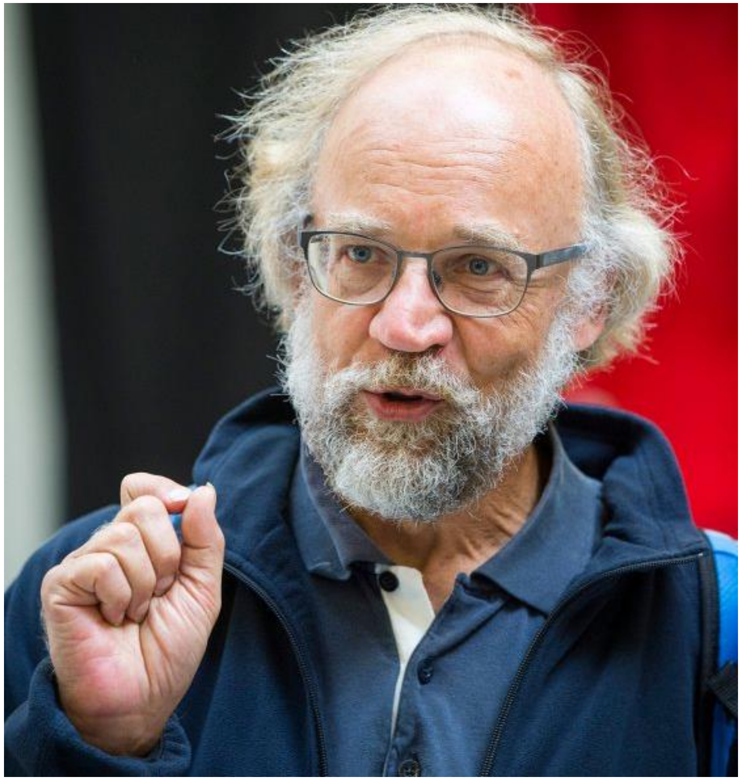
Martti Mäntylä

Aalto University

Martti Mäntylä – Back in business!

- Professor of Information Technology (Enterprise Systems), TKK & Aalto University 1987-
- Chief Strategy Officer, EIT ICT Labs 2009-2013
- Director, Helsinki Institute for Information Technology 1999-2008

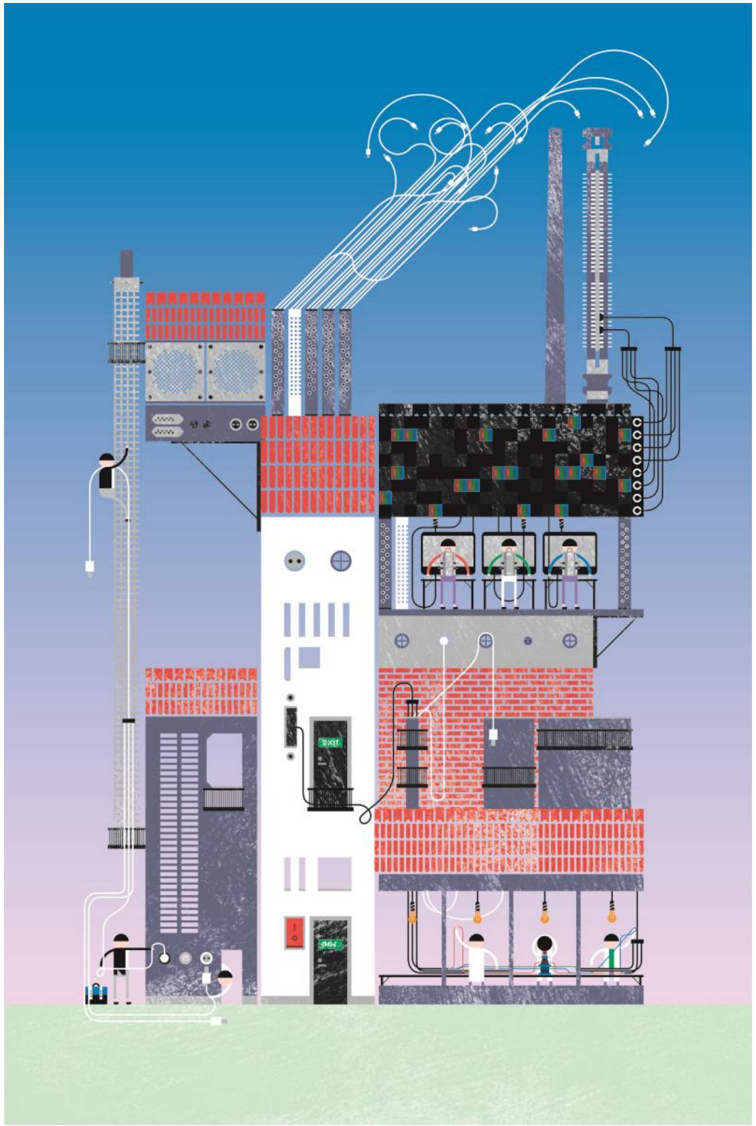
- Since 2014, catalysing Aalto's activities in Industrial Internet



Aalto Industrial Internet Campus

Innovation and *Encounters* backed up by *Research* and *Education*

http://aiic.aalto.fi



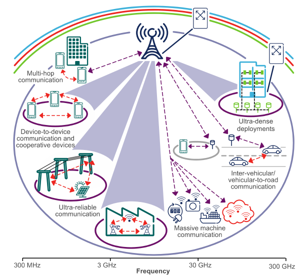
Aalto University

5G, Please Meet Industrial Internet

5G as an Industrial Internet Platform?

- Today, 4G/LTE architecture manages 2 billion mobile devices in a multiple actor environment, including sharing of business data across operators
- Can 5G provide a management architecture for 20 billion smart devices, including setting up "overlays" for industrial firms for data management and "joint clouds" for controlled data sharing across companies?
- If "yes", what should we do about it?

5G: Support for heterogeneous services



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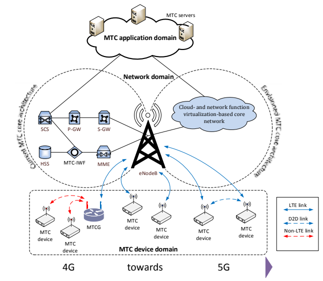
5G: Machine type communications



- Service and organization dependent virtualized EPC
- Edge computing

- Capillary networks
- Network controlled direct device-to-device

Aalto University

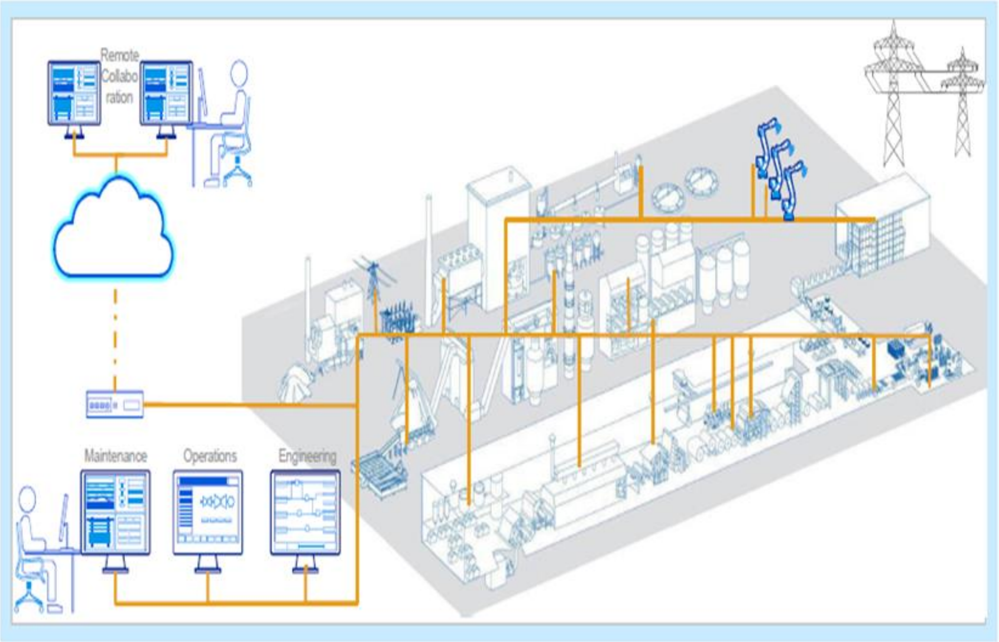
Business Case: Forest Industry

Share, analyze and utilize cross-enterprise data from a production line for win-win-win solutions

- Shared benefits across production life-cycle in
  - Engineering
  - Operations
  - Maintenance

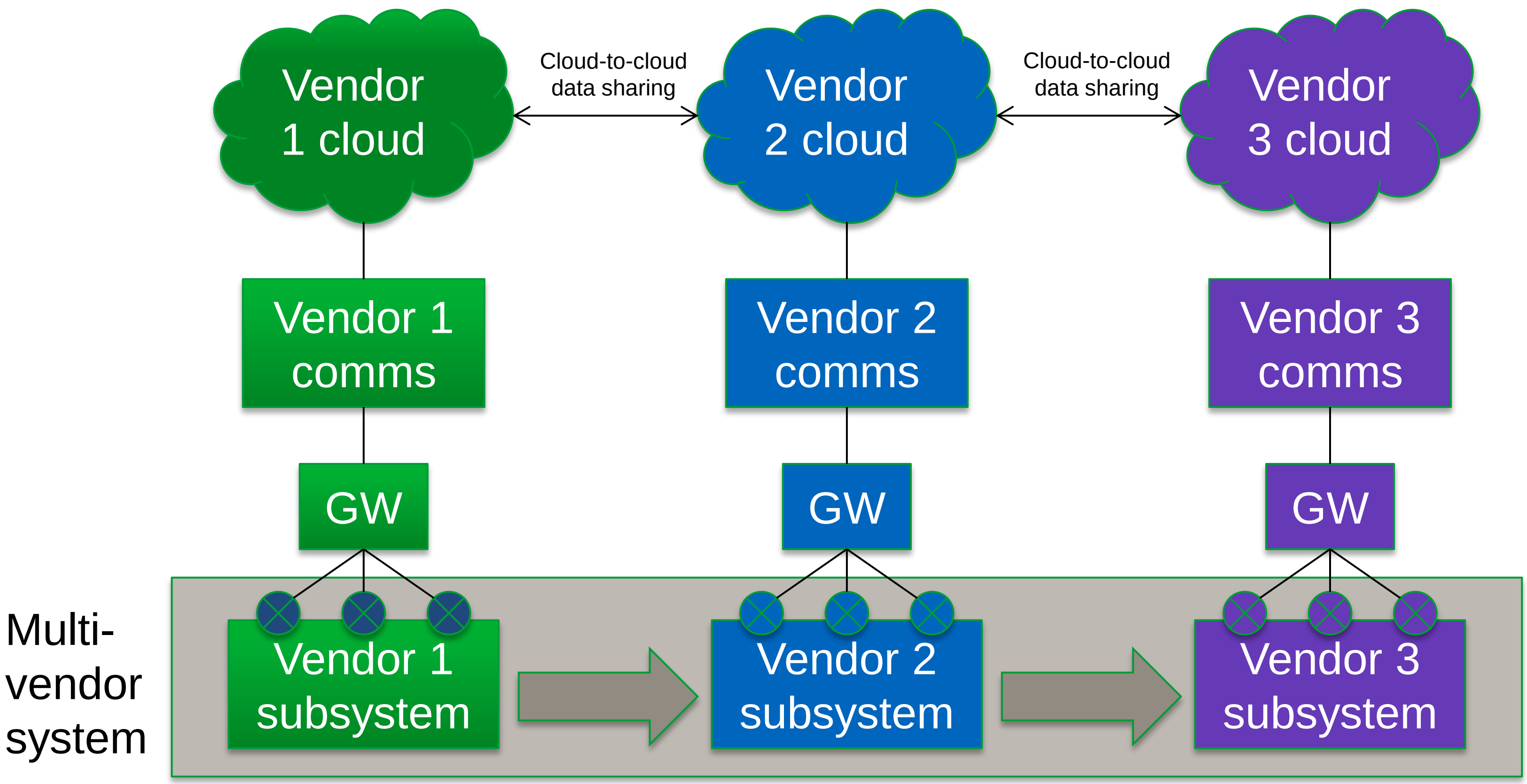
- Key characteristics of the solution
  1. Real-time data
  2. Mobile & remote operations
  3. Predictive actions
  4. Increased automation

- The scope covers all major functional units of the selected production line

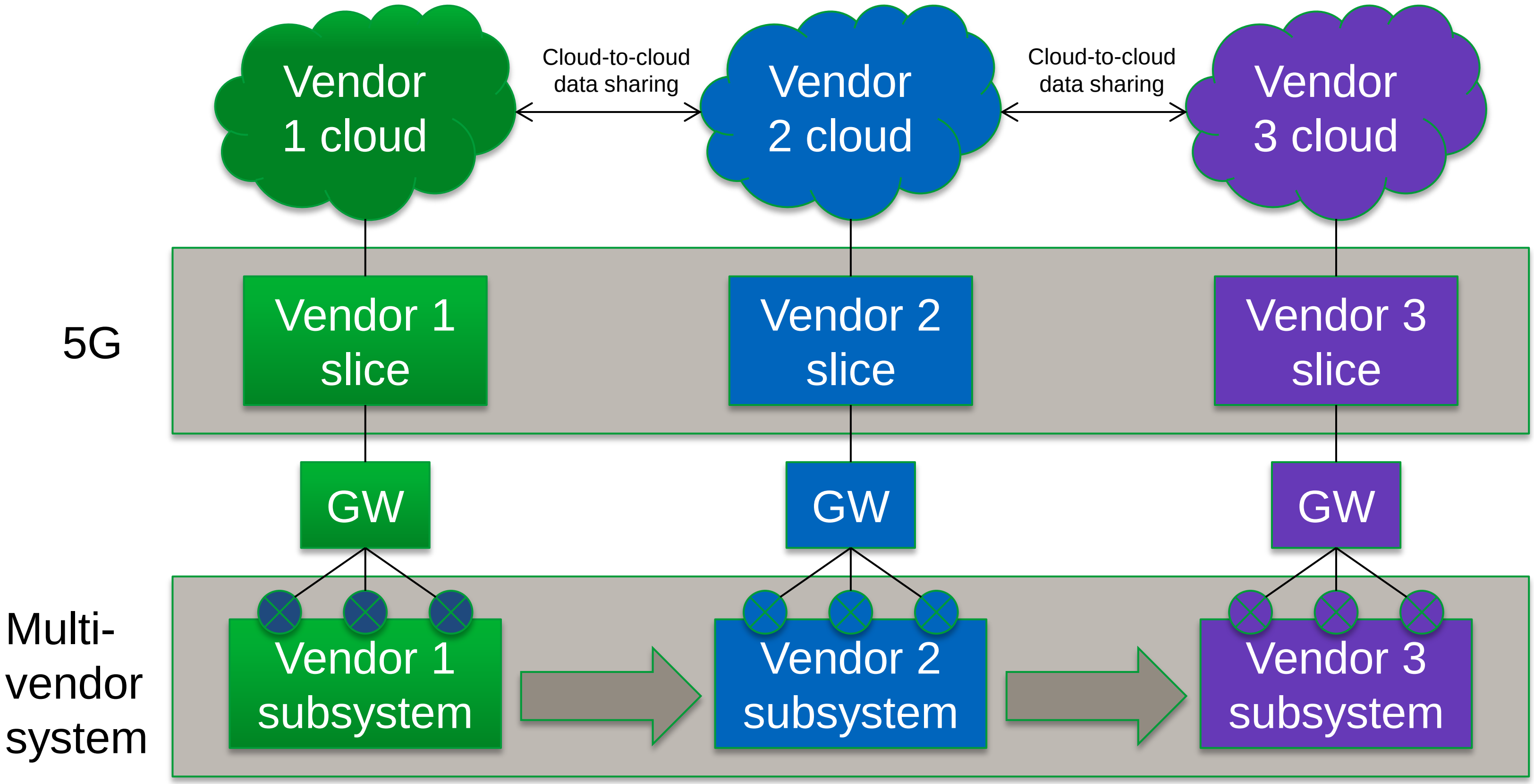


Open the sensor data of machines from a selected production line to boost operational innovations for all stake holders.

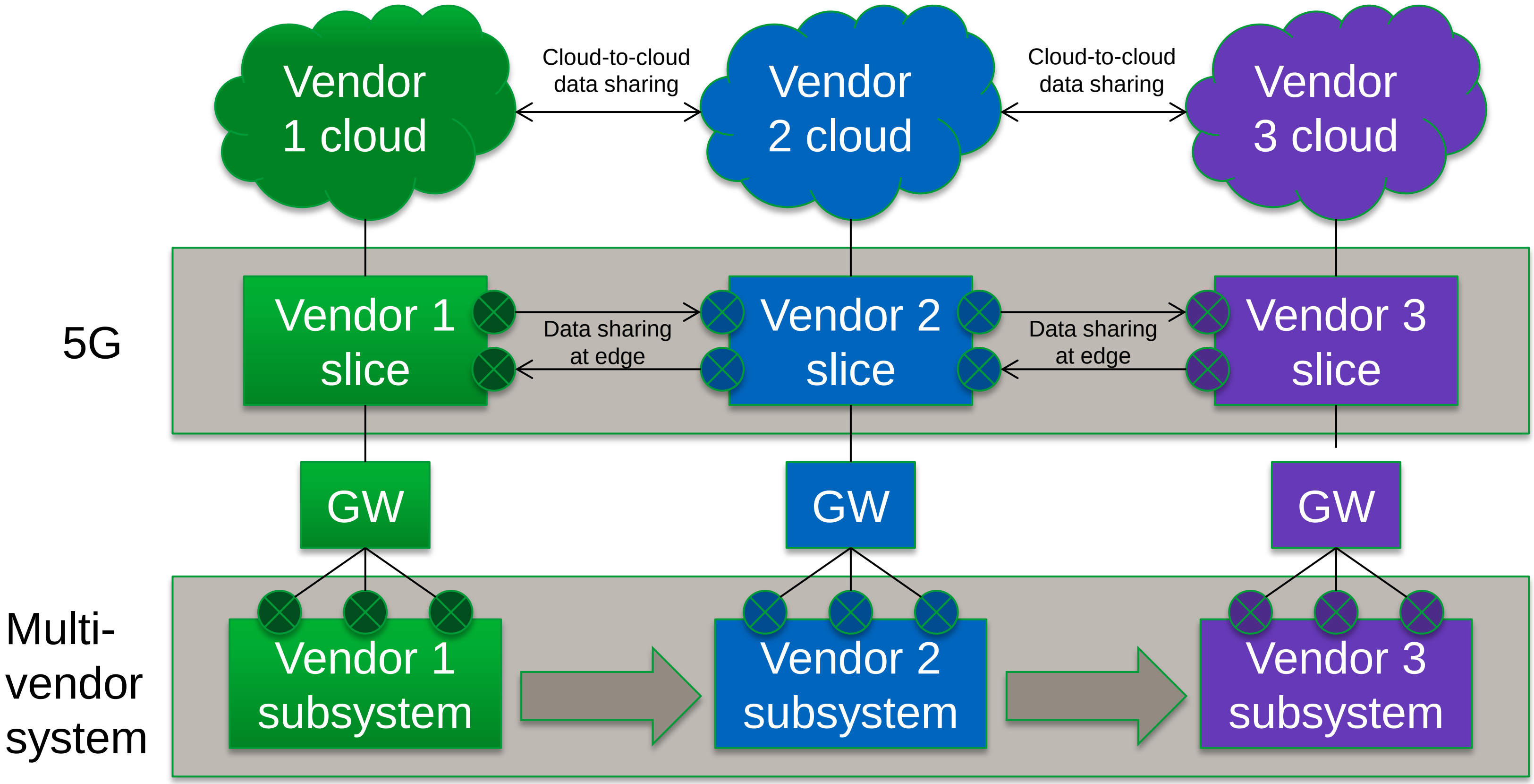
Present: Vertical silos



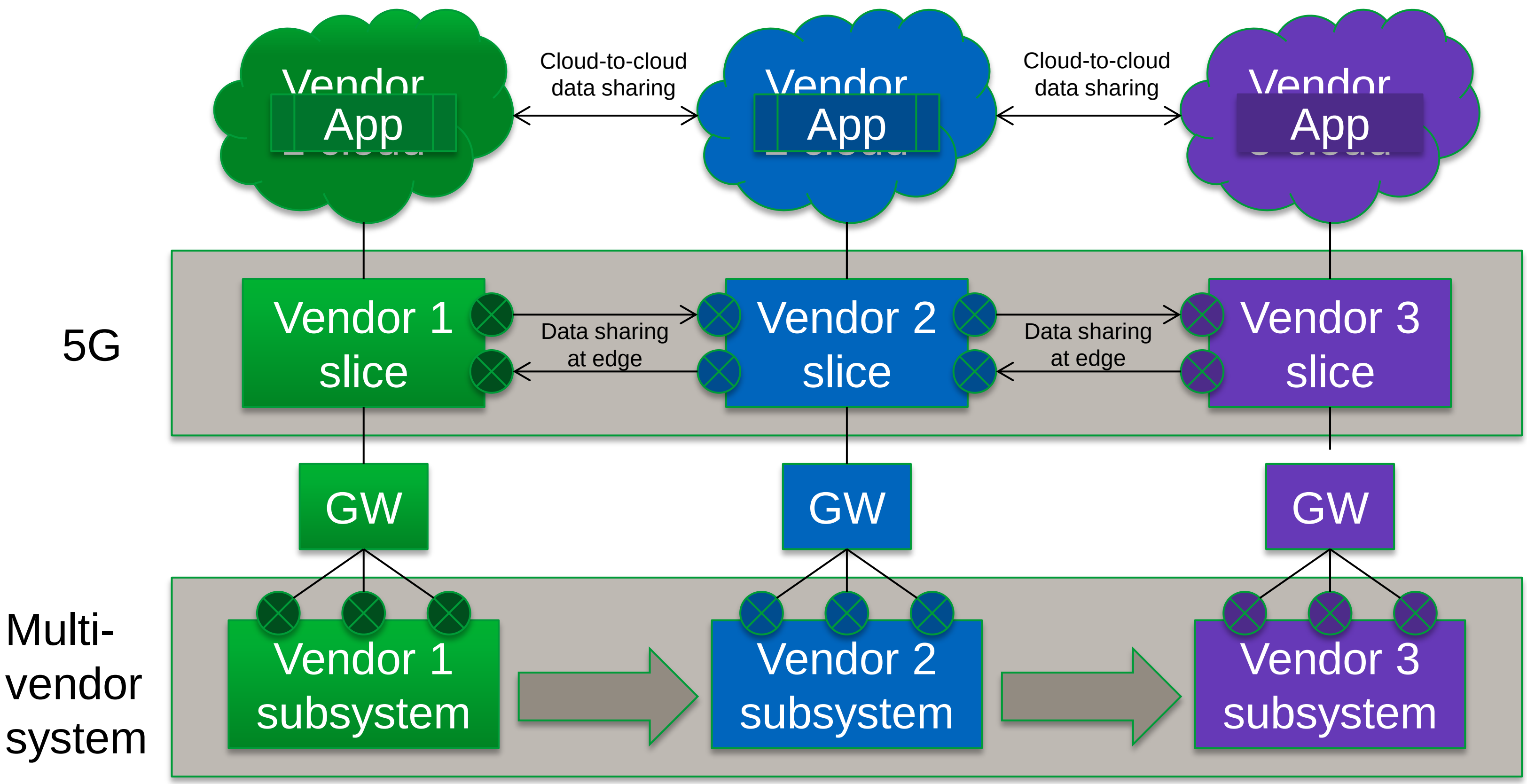
Future 1: Shared communications platform



Future 2: Shared communications platform with data sharing at edge



Future 3: Client applications at edge



5G@ll Project

Aalto University

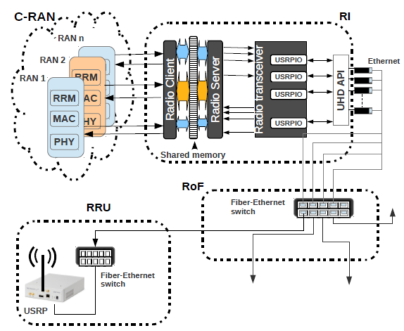
5G@II project

- Create a management system embedded in the 5G architecture that will support
  - secure management of the smart devices
  - scalable and secure data collection and storage on the basis of 5G network slicing
  - policy-based digital contracting, digital service creation and management
  - trustworthy data sharing using models rather than data itself.
- Pilot the system by combining the AIIC platform http://aiic.aalto.fi/en/ and TAKE-5 experimental 5G network (http://take-5g.org/) and running concrete experiments based on industrially relevant use cases.

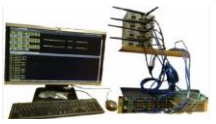
TAKE-5

5G research platform @Aalto

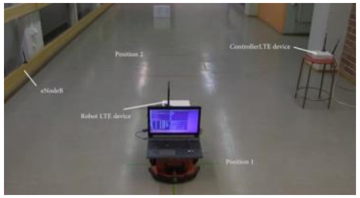
- Aalto TD-LTE testbed
  - Implementation of TD-LTE tesbed (Rel. 8) on general purpose processors and non-real-time operation system
    - Over 30 000 lines of C++ code
    - PHY and limited set of RRC and MAC functions
  - Cloud-RAN setup
    - Base station can run on virtual server
  - Flexible spectrum use
    - Can interact with Farispectrum geo-location data base
    - TVWS operation
  - DAS implementation
    - Antenna port selection
    - Open loop transmit diversity
  - D2D implementation
    - Network controlled D2D
    - Reliable D2D links
    - Underlay with IC
    - Mode selection
  - MTC MAC implementation
    - Compressive sensing based MAC with IC



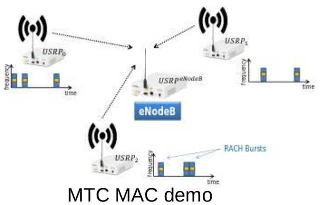
Cloud RAN architecture



eNodeB and RRU



D2D Robot control demo

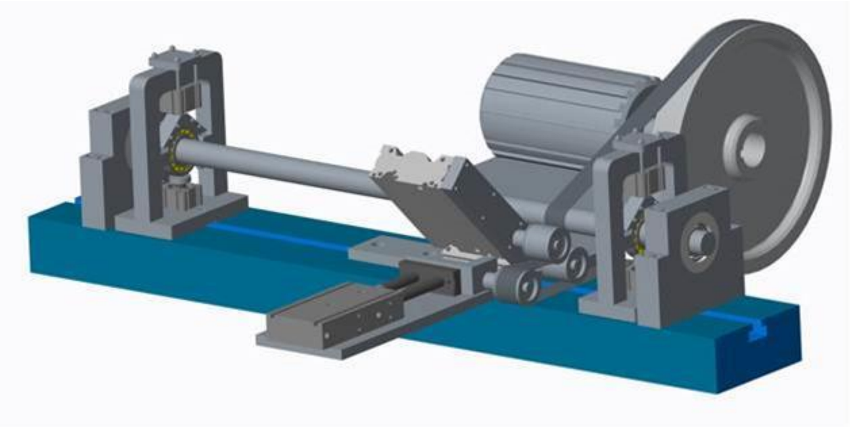


MTC MAC demo

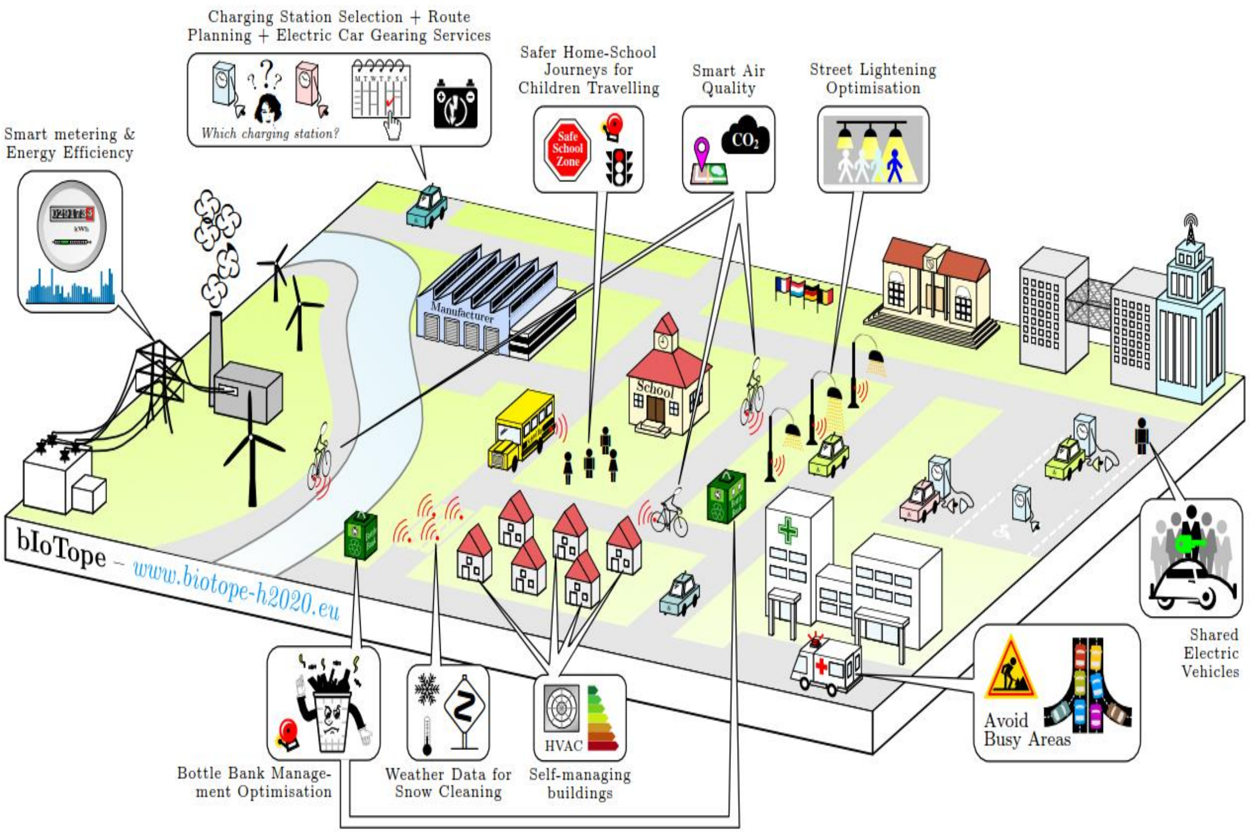
DAS demo

AIIC experimental platforms

- ABB: IoT instrumentation for a research apparatus for studying magnetic bearings
- Konecranes: Smart crane with extensive PLM models and IoT interfaces
- ABB et al.: Process control lab with several IoT-enabled unit processes
- ACRE: Digital campus



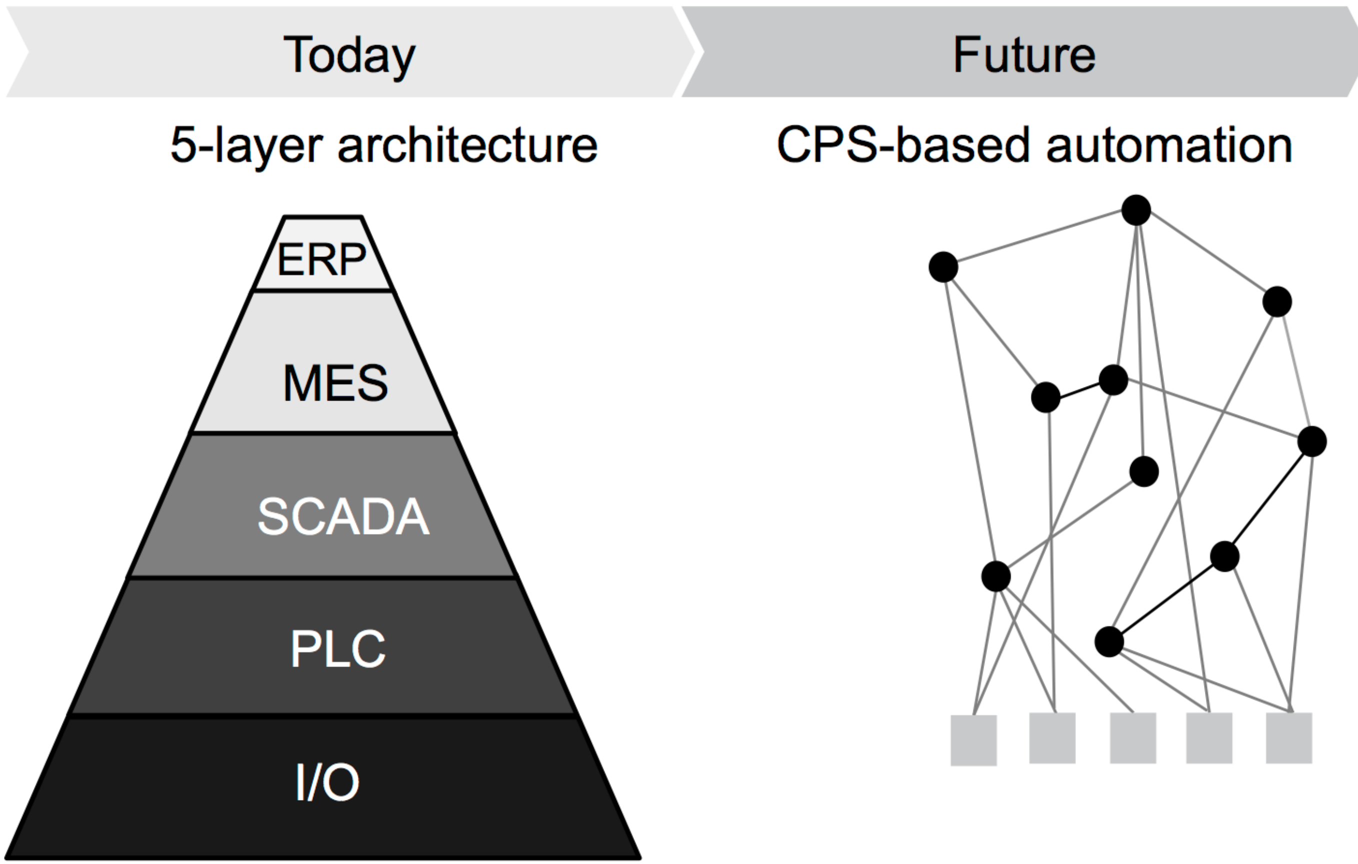
Digital campus: bIoTope project



Nomenclature

- “Factory”: shorthand for various kinds of production sites or pieces of physical infrastructure with a variety of equipment organised and managed as a whole
- “Equipment”: individual pieces of production equipment inside a factory, presently typically organised and managed with a hierarchical control structure (ERP, MES, SCADA, PLC)
  - With Industrie 4.0, the fixed hierarchical control may be replaced by a more flexible network of “components”
  - This opens the door for more flexible and agile control architecture (“control by cloud, and without ownership”)

From 5-layer architecture to autonomous cyber-physical systems



Data

- Production management data: Data on the material flow (inputs and outputs) through the factory and its equipment
- Control data: Used to control the direct operations of a factory and its equipment
- Diagnostic data: Used to monitor the performance of the operations of the factory and its equipment
- Engineering data: Lifecycle engineering data on the factory and its equipment (incl. design data, configuration data, maintenance histories, data on embedded software where relevant)
- Orthogonal categories of the above:
  - Personal data: Data related to persons operating the factory
  - Company data: Data related to the identity of the stakeholder(s)

Stakeholders / domains of governance

- Factory “owner”
- Factory operator (if distinct from owner)
- Shop floor operator
- Equipment provider
- Supplier(s) and customers
- Service providers
  - Incl. maintenance, engineering services
- Regulators, certification authorities
- Financial institutions
- Public domain

Use cases

- Factory control
  - Local / remote
- Factory monitoring
- Fleet management
- Digital twin
- Intelligent mobility

Factory control

- Enable control of factory equipment for industrial process optimization
- Local: E.g., private 5G network inside factory site
- Remote: E.g., network slice for data transmission between different production sites and other parties
- Stakeholders:
  - Factory owner: needs full access
  - Equipment providers: must grant access to the control features

Factory control

- 5G issues
  - Spectrum management
  - Latency (Especially to enable “remote control” by leveraging cloud-based approach)
    - On-demand provisioning of some "control" features at the edge of the network
  - Dynamic network and service chaining
  - Robustness and availability
  - Cyber security
  - Lifecycle management
    - New equipment, new control software versions, …
    - Esp. scenarios where equipment from many vendors needs to be managed and controlled in a single system

Factory monitoring

- Provide data for monitoring the performance of the factory and its equipment
  - (Some) control data, diagnostic data
  - Collect historical performance data for analysis and assessment
- Stakeholders:
  - Factory owner: full view
  - Equipment provider: partial view related to the specific piece of equipment (plus potentially relevant other data related to the use context) -> **fleet management**
  - Other stakeholders: e.g., regulative body, financial institution, factory supplier, factory customer, factory service provider

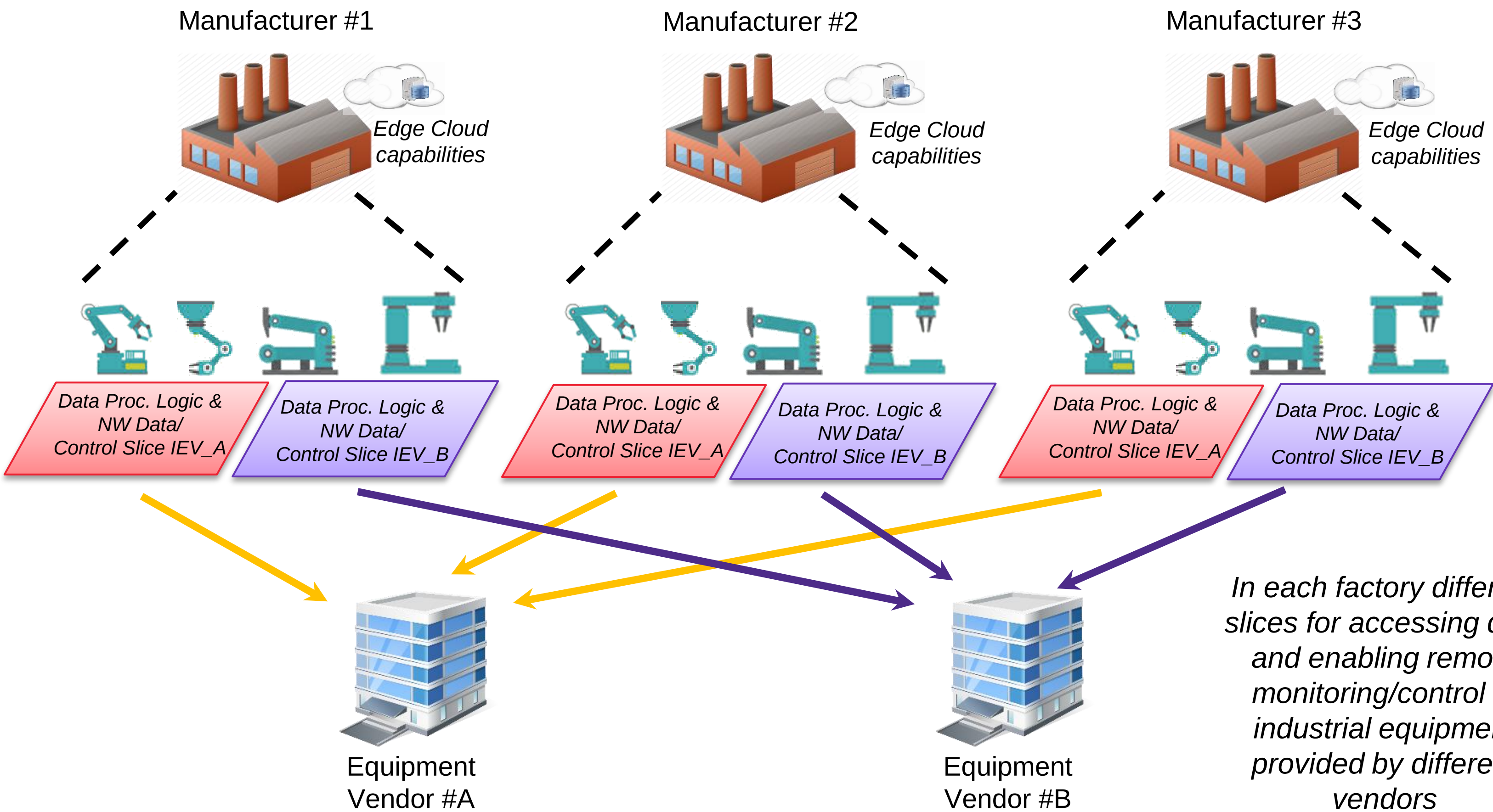
Factory monitoring

- 5G issues
  - How to provide several parallel views to the underlying factory data flows corresponding to the needs of various stakeholders and respecting the confidentiality requirements of each?

Fleet management

- Remote management of equipment by its provider
  - Diagnostics / predictive maintenance: Collect diagnostic data for fault prediction and assessment, guide maintenance operations
  - Life-cycle engineering: Collect diagnostic data to study how the operations can be improved by better design, optimising the control, improving the product configuration via some update, etc.), design and deploy updates
- Stakeholders:
  - Equipment providers: access to relevant data from installed base
  - Customers: need to grant access to relevant data
- 5G issues
  - How to provide access to all installed equipment on the field while respecting the confidentiality requirements of the customers?

Remote monitoring / fleet management



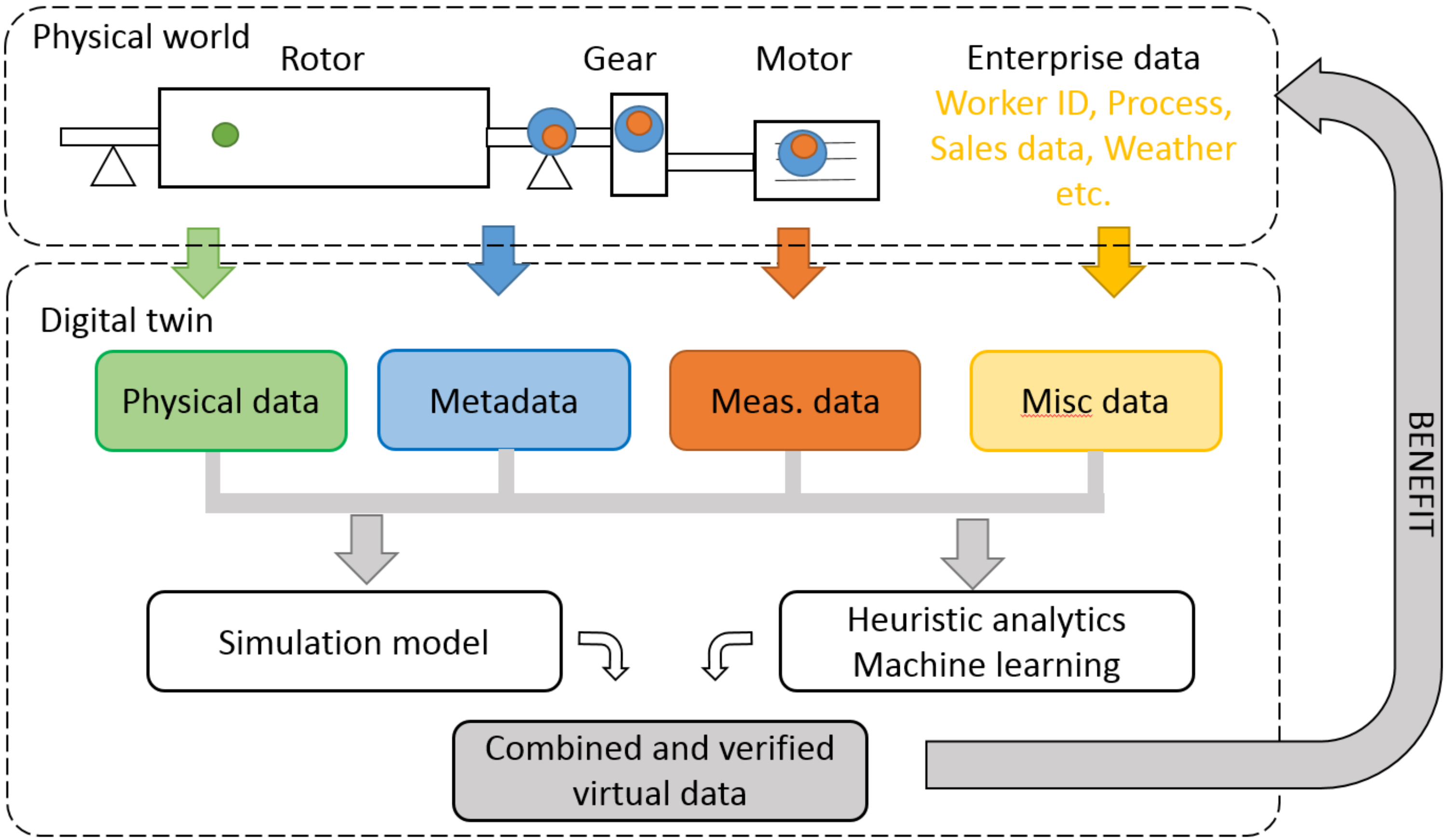
In each factory different slices for accessing data and enabling remote monitoring/control of industrial equipment provided by different vendors

Picture credit: Ivan Ferris & Tarik Taleb

Digital twin

- Build and maintain a comprehensive data repository representing a specific product instance across its whole lifecycle (design, manufacturing, installation, use, demolishing/reuse), e.g.
  - Rich design/engineering data such as simulation models and design rationales
  - Maintenance history
  - Time-series data of embedded sensor readings

Digital twin



Intelligent mobility

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- News
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Henry Ford Trust and Aalto University to cooperate on smart traffic research

LISTEN

02.06.2017

A networked traffic system offers possibilities to streamline traffic safety, mobility services, and traffic, especially in urban environments.

Henry Ford Trust will support Aalto University's research project on smart traffic with a four-year funding. The extent of the whole project is about 700 000 euros, of which the trust will now fund the first year and the purchase of a research car. When realised in its entirety, the trust's funding enables three four-year doctoral theses on the field of smart traffic.

The trust also annually awards grants for several Master's and other theses.

"Aalto University's interdisciplinarity is a strength in researching future technologies and their applications. The study of smart traffic and mobility is closely tied to digitalisation, new energy solutions, and built environment, which are our strengths", says Dean **Gary Marquis**.

"Committed research, building networks, international cooperation, and systematic utilisation of information multiply the effectiveness of the investment", states **Hannu Pärssinen**, the chair of the board of Henry Ford Trust.

Use cases vs. AIIC experimental platforms

	Smart crane	Process plant	Building mgt
Factory control	M2M scenarios with strict latency requirements	Remote control scenarios with strict latency requirements	System-level control of devices from multiple vendors Equipment life-cycle management
Factory monitoring /fleet management	Managed access to relevant data to the equipment provider Partial access to relevant data to other stakeholders	Managed access to relevant data to the equipment providers	Managed access to relevant data to the equipment providers
Digital twin	Data integration scenarios including sensor data	On-line simulation & control scenarios	On/off-line simulation and control scenarios

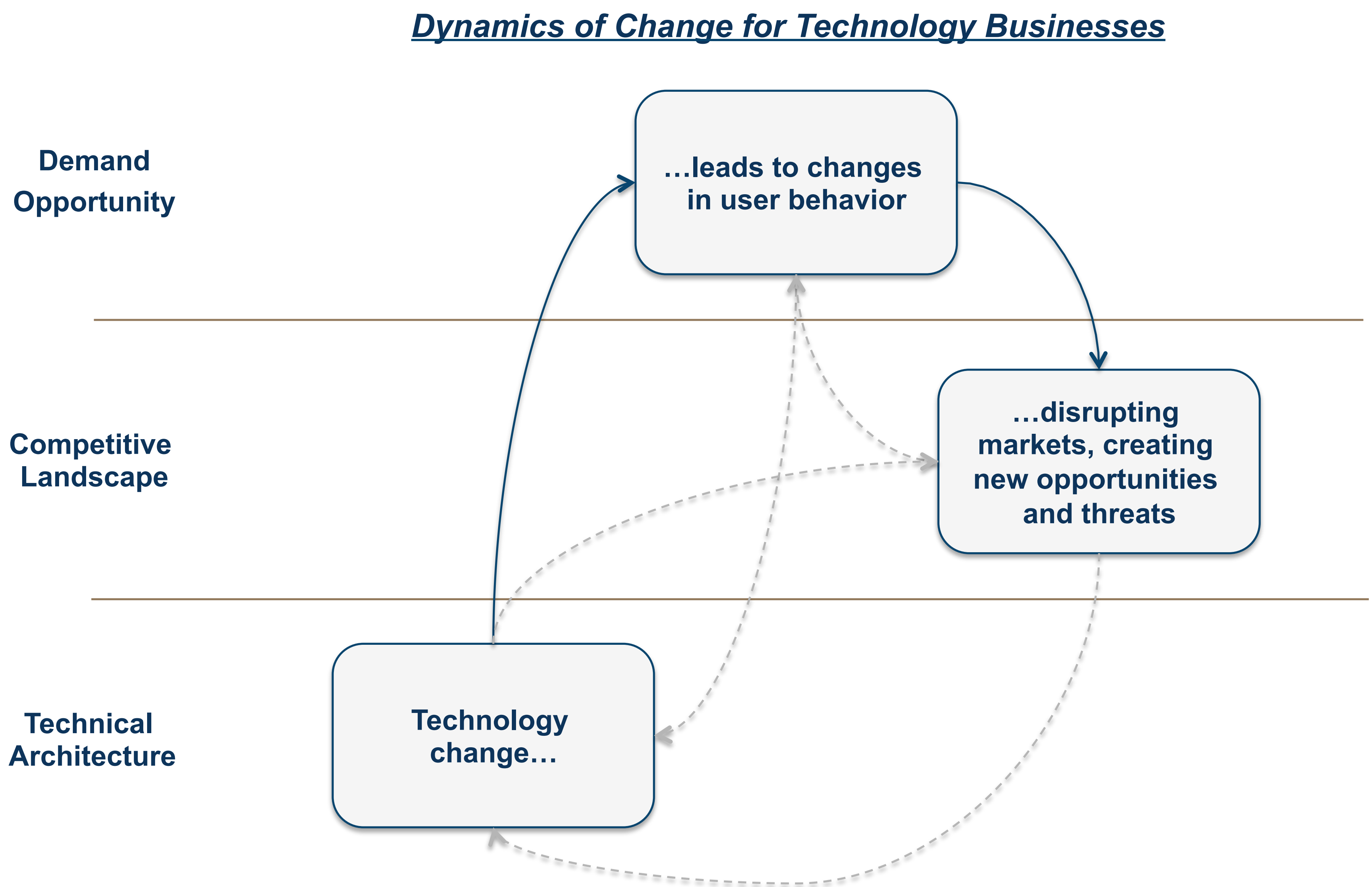
Comments and questions welcome!

Altman Vilandrie
& Company

The Transition to 5G and the Internet of Things

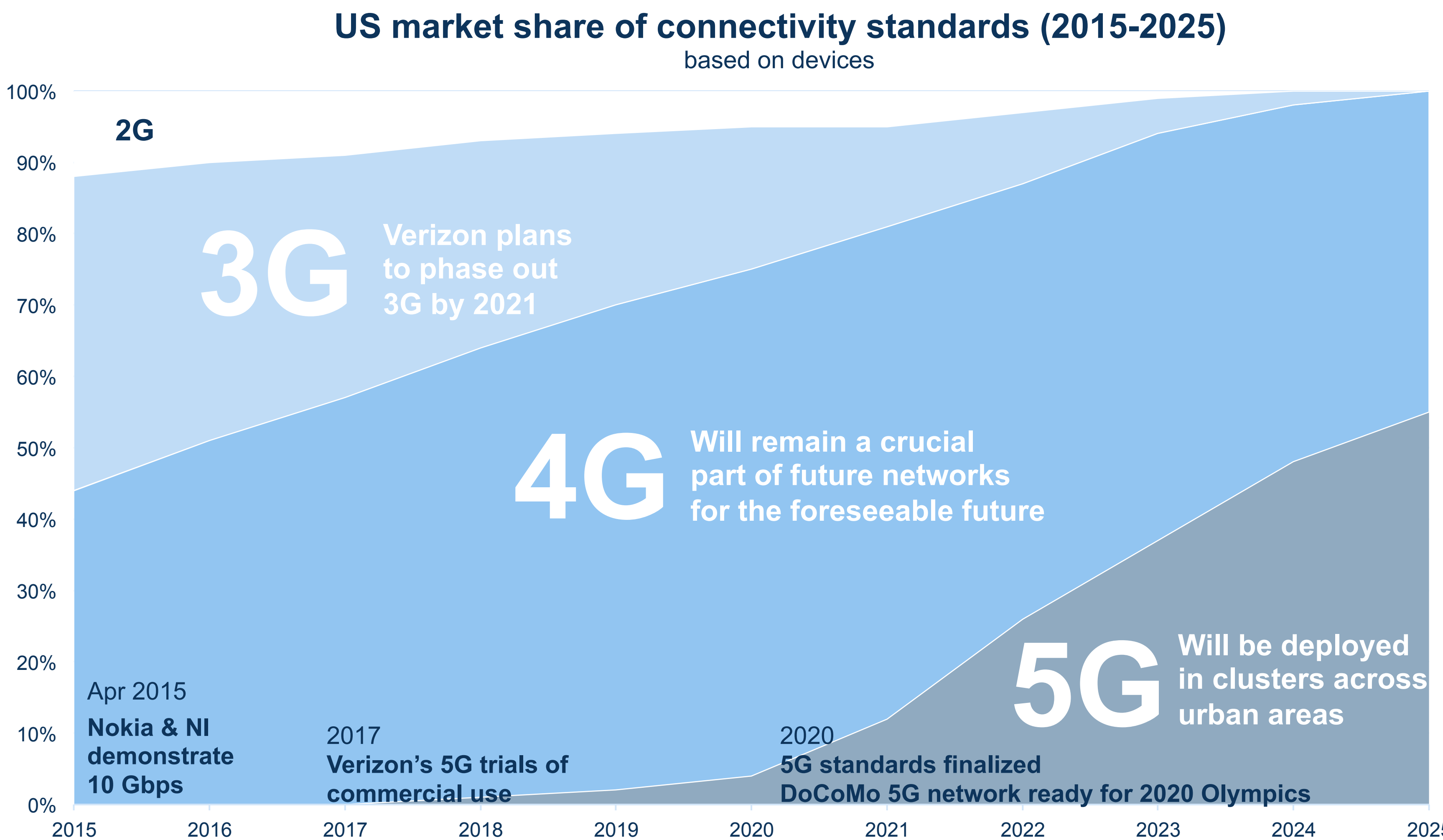
June 10, 2016

Effective strategy begins with understanding how technology evolution and changes in user behavior create new opportunities and challenges for businesses



Evolution of Wireless Networks

US wireless networks will shift from 4G LTE to 5th Generation (5G) wireless solutions over the next 5-10 years

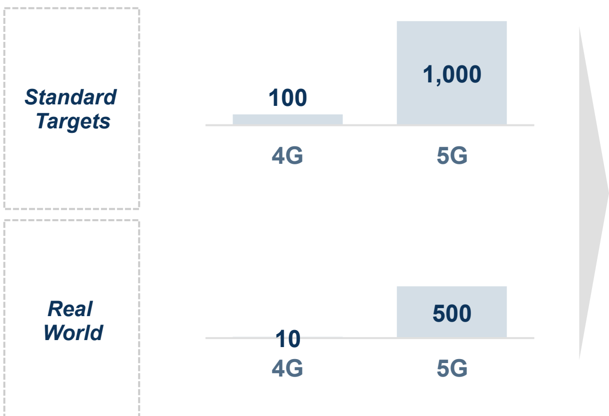


Sources: GSMA Intelligence; DoCoMo; 3GPP

Performance of 5G vs. 4G

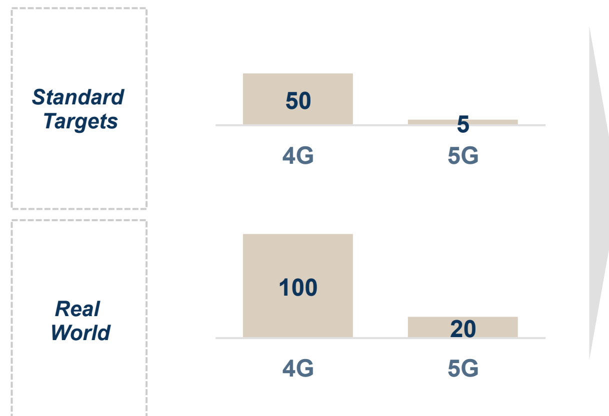
5G will provide a number of benefits: Super fast wireless broadband, lower latency, much greater capacity, and the ability to handle many many more devices

Avg. Download Speed *(Mbps)*



10 - 100x improved downloads speeds

Avg. Roundtrip Latency *(milliseconds)*

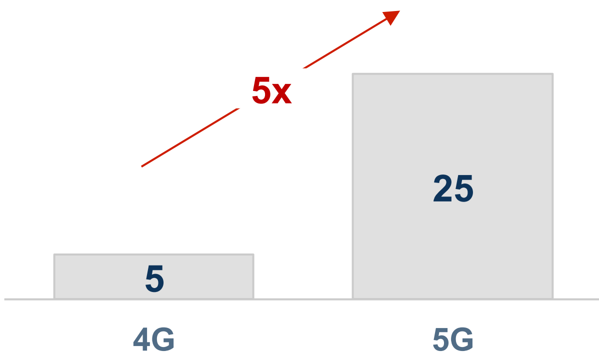


5-10x improved latency

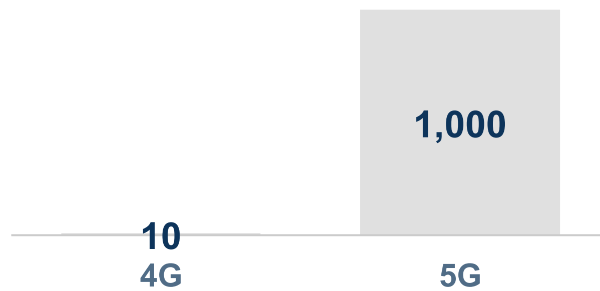
Sources: Nokia 5G Deployment White Paper; Samsung: 5G Vision;
Scenarios for 5G Mobile and Wireless Communications: The Vision of the METIS Project (IEEE Communications Magazine, May 2014)

At first 5G will be primarily in urban and dense-suburban areas – and used for fixed wireless to deliver home broadband

Small Cell Density
(Small Cells = Macro Cell Coverage)



Throughput Capacity
(Gbps/km2)



- 5G will require many more sites to cover the same area – deployment economics will be challenging in rural areas
- But 5G also will have many times the capacity
- This makes 5G an excellent solution for urban capacity challenges
- And the high costs require new sources of revenue, making home broadband an attractive market opportunity

This is happening first in the US, ahead of standards, because of unique competitive dynamics of this market

Cable Companies

Wireless Carriers	No Mobile Offer	Mobile Offer
Home Broadband	**Wireless Wins**	**Both Improve**
No Home Broadband	**Today's Market**	**Cable Wins**

Competitive Dynamics are accelerating the move to 5G

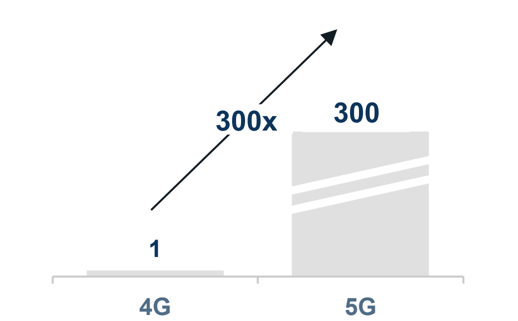
- Wireless companies are moving into home broadband with 5G
- Meanwhile, cable companies are moving into mobile with WiFi and potentially new spectrum or partnerships
- If one moves and the other doesn't, then there is a large opportunity
- If both move, then they are still likely better off due to bundling and higher ARPUs and the opportunity to change the competitive dynamice

In the long-run, however, 5G's other benefits will help unleash the Internet of Things

5G Connectivity

Max Simultaneous Connections per Cell

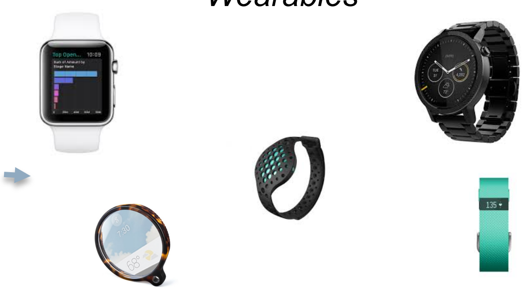
(000s connected devices)



Smartphone as 'Life Controller'

Internet of Things

Wearables



Connected Car

Connected Home

New Interaction Models

As we move from the smartphone world to the Internet of Things, new interaction models, including voice, multi-modal, and autonomy, will become much more prevalent

From → ***To***

Smartphone as 'life controller'	***Automation***	***Voice***	***Multi-modal***

Examples…

Google Now

Nest

Amazon Echo

Siri and OK Google

New Competitive Landscape

A handful of key players are battling over who will control this new multi-device, multi-modal user experience – and all are investing millions in these user interfaces

	Platforms / Intelligence	Distribution / Services	Devices	Apps / UI	Investment Summary
Apple	Siri *$200M, 2014*; HealthKit 2014; ResearchKit 2015; Apple CarPlay 2015; HomeKit 2015; CareKit 2016; *3 other speech tech / personal assistant acq., $50M+*		Watch 2015	HealthKit 2014; Apple CarPlay 2015; HomeKit 2015	$250M+, 4 deals, 7 products
Google	android wear 2014; android auto 2015; Brillo 2015; nest *$3.2B, 2014*; Google Self-Driving Car Project; Google Assistant 2016; *1 other acq., undiscl*		Glass 2014; nest *$3.2B, 2014*; dropcam *$555M, 2015*; Google Self-Driving Car Project; Google Home 2016; *1 other aq., undiscl.*	nest *$3.2B, 2014*; android auto 2015	$3.8B+, 4 deals, 9 products
amazon	amazon alexa *$250M, 1999*; 2lemetry *IoT Platform Undiscl., 2015*; safaba *Text translation Undiscl., 2015*; AWS IoT Platform 2015; Orbeus *AI image recog. Undiscl., 2015*		amazon echo 2014; Echo Dot – 2016; Amazon Tap – 2016		$250M+, 4 deals, 5 products, strong recent hiring
Facebook	Parse *$85M, 2013 To be shut down 2017*; wit.ai *Undisclosed, 2015*			Moves *Fitness tracker app Undisclosed, 2014*	$85M+, 3 deals
SAMSUNG	SmartThings *$200M, 2014*; Connect Auto 2016		Samsung GALAXY Gear 2014; SmartThings *$200M, 2014*; Connect Auto 2016; • Home Appliances • Smart TVs	Samsung GALAXY Gear 2014; *$200M, 2014*; Connect Auto 2016	$200M, 1 deal, >5 products

Implications for Accessibility / M-Enablement – initial thoughts

Likely Benefits From 5G

- Multi-model cross device and applications and user interfaces will provide **more choice and flexibility** in how customers can interact with services
- **Proactive, intelligent and context aware** applications and services will improve the user experience / make things easier to use
- **Autonomous devices and systems** will reduce time required to get value out of technology
- **Low latency and high bandwidth** will improve performance and the types of applications that can be supported

Risks from 5G

- **Inconsistent availability and capabilities** from networks and services
- **Mass market consumer services may get ahead** of healthcare, regulation, and funding options
- **Reliability of 4G and 5G** may remain inferior to 2G or wired solutions
- **Expensive hardware** for new solutions that aren't mass market

Back up…

This performance will enable a broad set of new use cases for wireless networks, including most of the key uses for home broadband services

			Assessment		
	Applications	**Key Requirements**	**4G**	**5G**	**Details**
Today's Applications	**HD Video Streaming**	Download: 5 Mbps	✓	✓	Speed varies greatly with distance in 4G networks, but less in 5G
Today's Applications	**4K Video Streaming**	Download: 20 Mbps	✗	✓	5G's expected real world 500 Mbps will exceed requirements
Today's Applications	**Online Console Gaming**	Latency: <50 ms Reliability: >99.9%	✗	✓	5G's target is 99.999% reliability, but real world latency performance is unknown
Future Applications	**Cloud Gaming**	Latency: <50 ms	✗	✓	Unknown real world latency performance
Future Applications	**Virtual or Augmented Reality**	Latency: <10 ms	✗	uncertain	Issues may arise during peak hours or congested areas
Future Applications	**Future Household:** Simultaneous multiple 4K streams, VR, gaming sessions, etc.	Bandwidth: 100-200 Mbps	✗	uncertain	It may be possible to develop a 5G-to-the-home approach, but real world performance is key

Sources: Oculus, Twitch, Netflix, Verizon 4G LTE White Paper

5G Key Tech Advances

5G is not a single technical innovation, but a set of advances and approaches that taken together create breakthrough performance improvement

			Capacity	Performance	Costs
Spectrum / RF	***Use of cm/mm Waves at very high frequency ~2.5GHz+***	**Enables high spatial reuse and throughput** **Key enabling tech:** ▪ Wider spectral bands ▪ Massive-MIMO antenna designs ▪ Beam-forming	✓	✓	✘
Cells	***Filtered OFDM***	**More robust signal:noise processing** reducing the need for guard bands, increasing QAM (256+), increasing bandwidth	✓	✓	✓
	Carrier Aggregation?	**Enables use of contiguous and non-contiguous spectrum allocations** *(also used in LTE-A)*	~	✓	✓
Network Architecture	***Network Function Virtualization***	Enables **flexibility, cloud-like versatility, and software-upgradeability** of network components, reducing costs	~	✓	✓
	Core Control at the Edge	Less backhaul, lower latency, improved reliability from **local routing and CDN-like storage at the edge** of the network	✓	✓	✓

4G/5G Standards Evolution Timeline

The evolution to 5G will consist of updates to the LTE standard together with new radio-access technology

Today	*2016*	*2017*	*2018*	*2019*	*2020+*

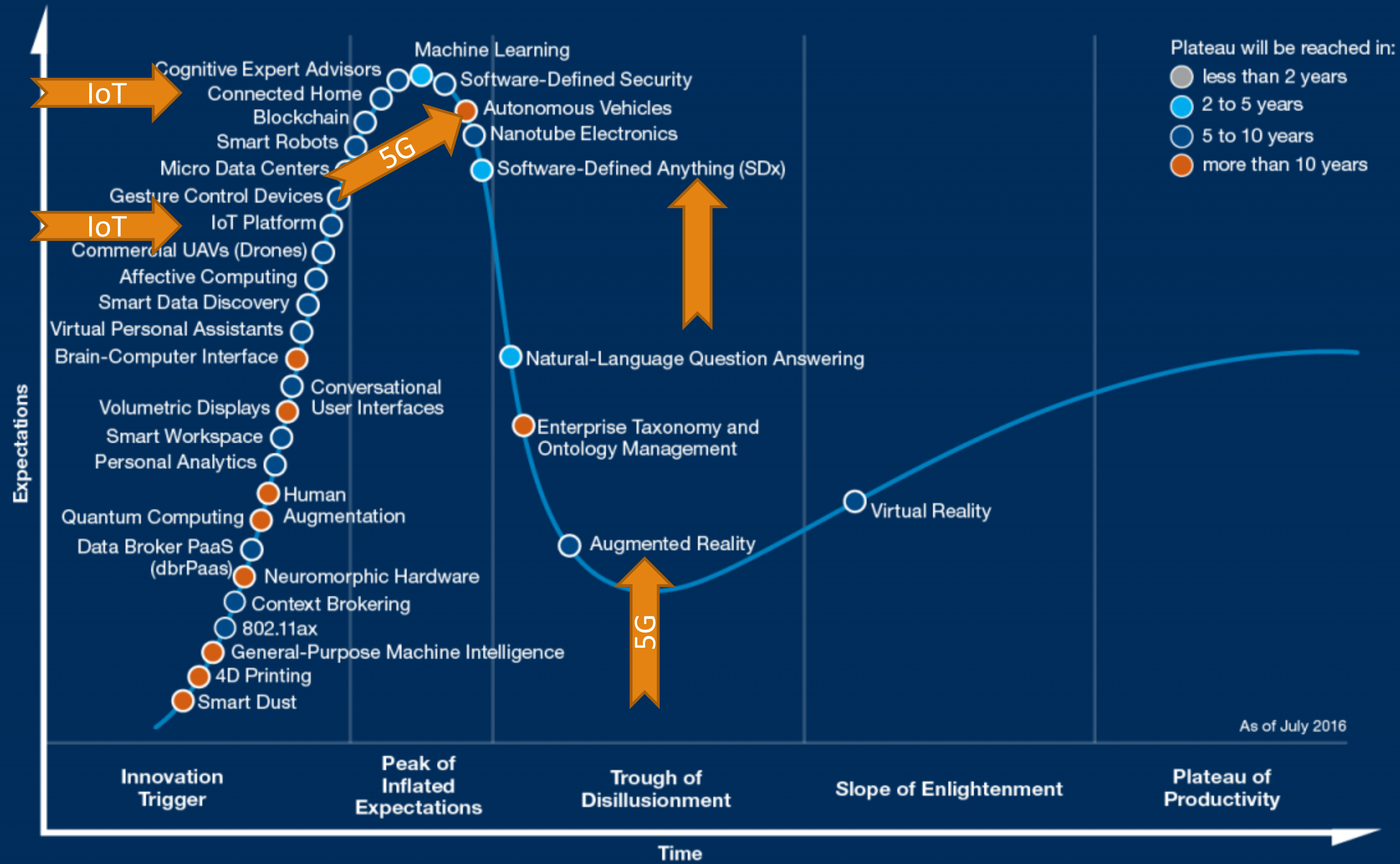
Release 13 Primarily LTE Enhancements *(Mar '16)*	Release 14 *(2017)*	Release 16 *2019*
▪ **Active Antenna Systems** ▪ **Elevation Beam-forming and Full Dimension MIMO** ▪ **Carrier aggregation** ▪ **Licensed-Assisted Access** ▪ **Massive machine-type comm.** ▪ **D2D communication** ▪ **Single-cell Point-to-Multipoint (SC-PTM)** ▪ **Enhanced signaling for coordinated multi-point (CoMP)**	▪ **Latency reduction:** Instant uplink access where transmissions can occur w/o prior request-grant, shorter transmission-time interval, <0.5 ms ▪ **Unlicensed spectrum:** extension of license-assisted access; support for transmissions in unlicensed spectrum ▪ **Intelligent Transportation Systems (ITS):** V2V and V2I communication ▪ **Massive machine-type communication:** OTA SW updates and P2P relays for coverage ▪ **Massive MIMO:** expanding to more than 16 antennas (currently up to 64 being explored)	▪ **Tight integration** between LTE and 5G radio access tech; beyond 'traditional' handover and may build on carrier aggregation frameworks ▪ **Ultra-lean design 'always on'** signals are kept to an absolute minimum to reduce energy consumption and interference ▪ **Multi-site connectivity for** enhanced data rates at the edges

5G and IoT - Separating Hype from Promise

HENNING SCHULZRINNE

The views and opinions expressed in this presentation are those of the author and do not necessarily reflect the official policy or position of any agency of the U.S. government. Any resemblance to actual policies, living or dead, or actual events is purely coincidental.

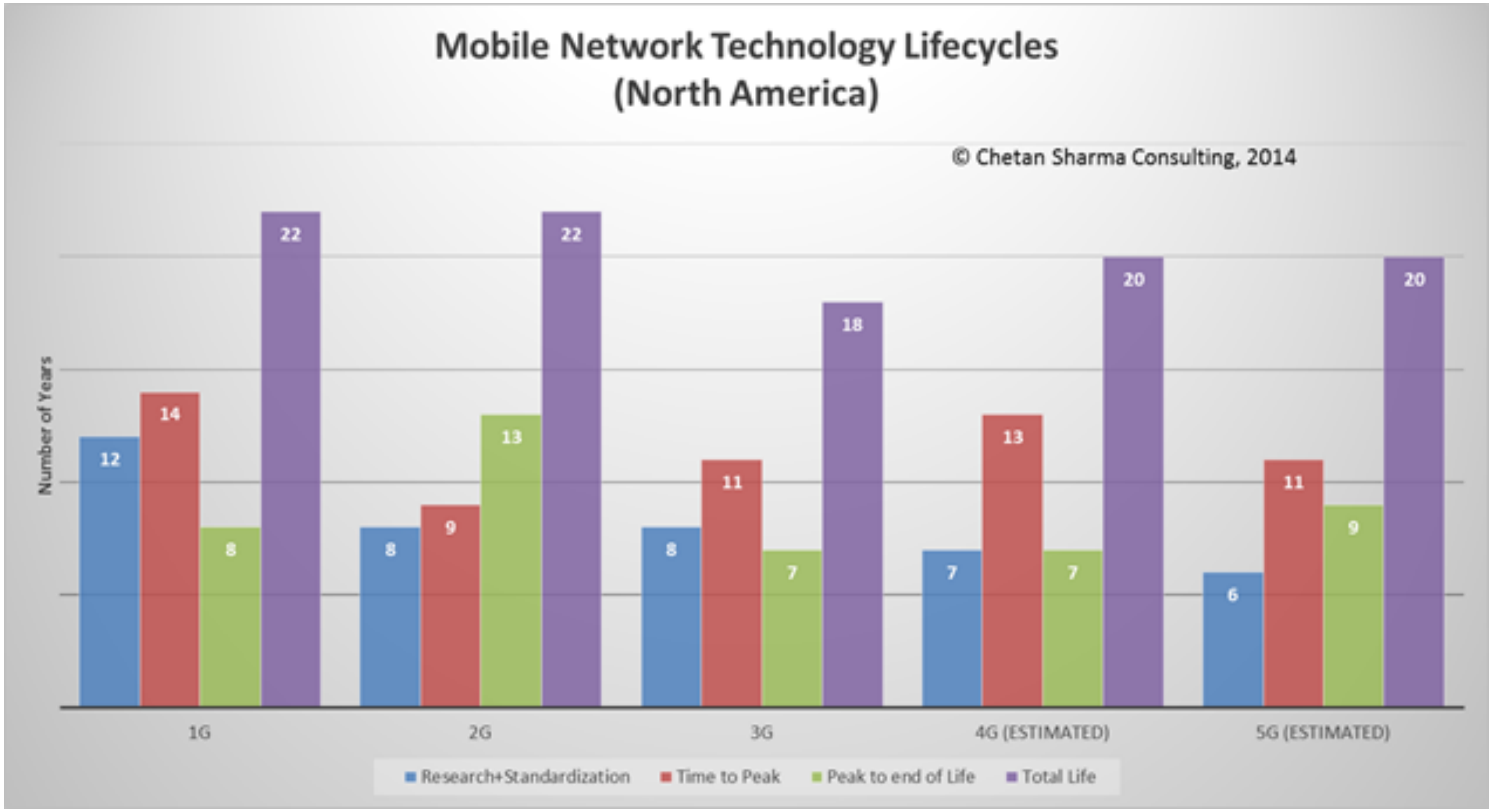
Gartner Hype Cycle for Emerging Technologies, 2016



Source: Gartner

Gartner

Design for 20 years



Generations are distinct

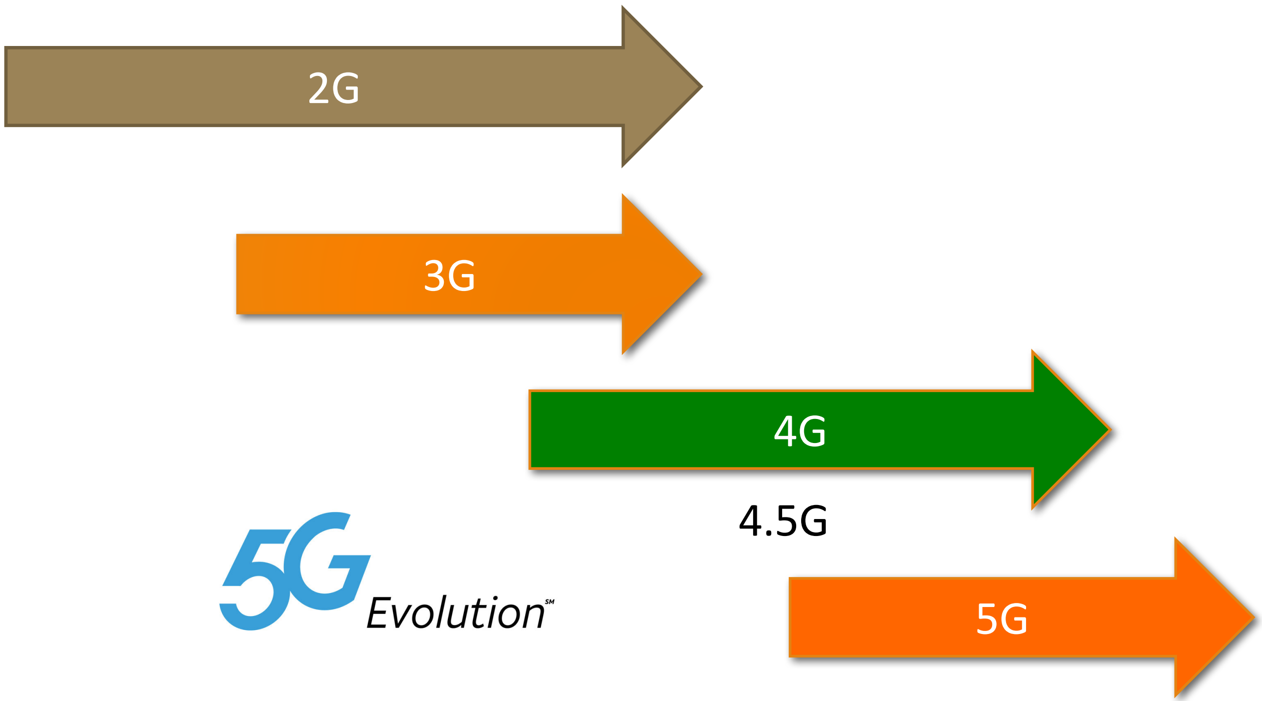
Talking a different language

	Maturists (pre-1945)	Baby boomers (1945-1960)	Generation X (1961-1980)	Generation Y (1981-1995)	Generation Z (Born after 1995)
Formative experiences	Wartime rationing Rock'n'roll Nuclear families Defined gender roles – particularly for women	Cold War 'Swinging Sixties' Moon landings Youth culture Woodstock Family-orientated	Fall of Berlin Wall Reagan/Gorbachev/Thatcherism Live Aid Early mobile technology Divorce rate rises	9/11 terrorists attacks Social media Invasion of Iraq Reality TV Google Earth	Economic downturn Global warming Mobile devices Cloud computing Wiki-leaks
Percentage in UK workforce	3%	33%	35%	29%	Employed in either part-time jobs or apprenticeships
Attitude toward career	Jobs for life	Organisational – careers are defined by employees	"Portfolio" careers – loyal to profession, not to employer	Digital entrepreneurs – work "with" organisations	Multitaskers – will move seamlessly between organisations and "pop-up" businesses
Signature product	Automobile	Television	Personal computer	Tablet/smartphone	Google glass, 3-D printing
Communication media	Formal letter	Telephone	E-mail and text message	Text or social media	Hand-held communication devices
Preference when making financial decisions	Face-to-face meetings	Face-to-face ideally but increasingly will go online	Online – would prefer face-to-face if time permitting	Face-to-face	Solutions will be digitally crowd-sourced

Source: Barclays, University of Liverpool

land line	2G	3G	4G

Generations overlap



Generational surprises

Generation	Expectation	Surprise
2G	better voice quality ("digital!")	SMS
3G	WAP	web
4G	IMS	YouTube, WhatsApp, notifications
5G	IoT (low latency)	?

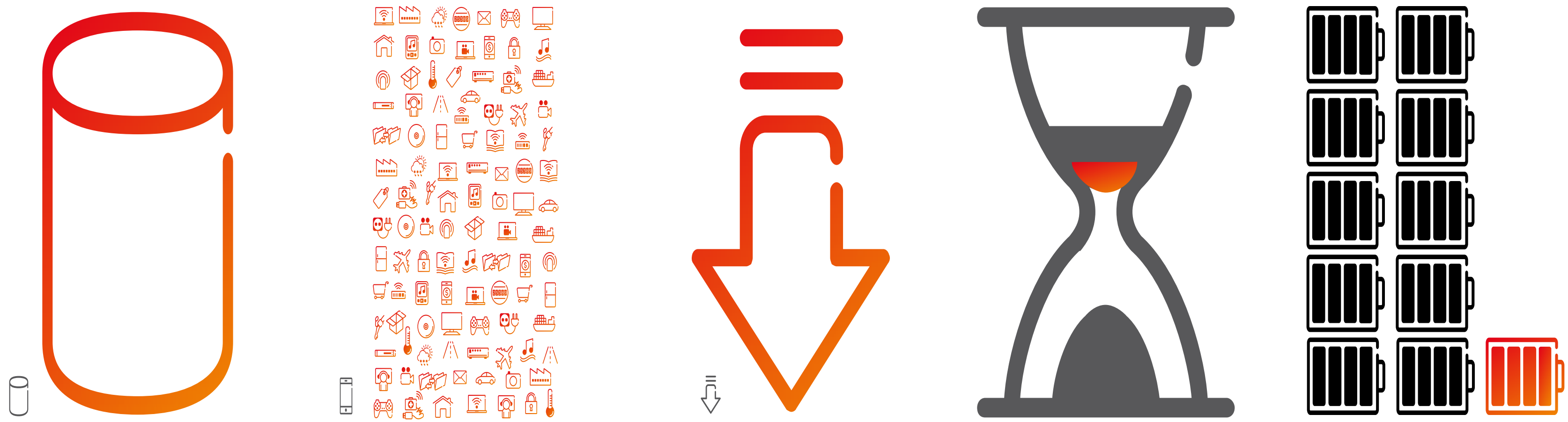
underestimated cost and fixed-equivalence as drivers

Lessons, in brief

Experience	Lessons
VoLTE, IMS	avoid complexity avoid entanglement plan intercarrier interfaces
Wi-Fi	don’t trust the RAN/AP
disaggregation of functions	clear & simple interfaces don’t assume trust between elements
app stores	keep it application-neutral
FTTH, backhaul cost	re-use backhaul where you can find it

METIS Technical Objectives

1000x data volume	50/500 B devices	Up to 10Gbps	Few ms E2E	10 years



1000x	**10-100x**	**10-100x**	**5x**	**10x**
higher mobile data volumes	higher number of connected devices	typical end-user data rates	lower latency	longer battery life for low-power devices

METIS, "Toward a 5G Mobile & Wireless System Concept"

2G → 3G → 4G → 5G ➔ increasing number of technology components

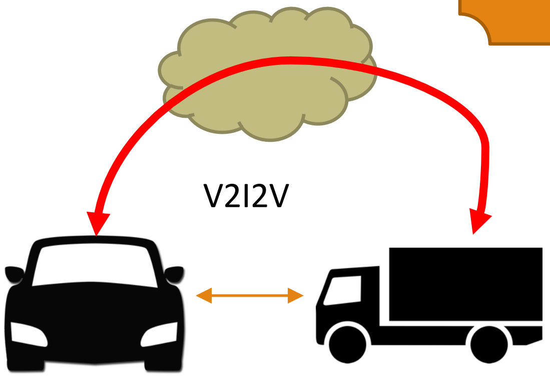
5G is a systems standard

Technology component	Proposed application	Less exciting, but likely
mmWave	10 Gb/s user rates	capacity in stadiums fixed wireless?
edge computing	IoT	video caching
M2M	billions & billions of devices! autonomous vehicles!	electric meters
1 ms latency	autonomous vehicles!	keep it application-neutral
slicing	QoS	test networks, VPNs

GENI

5G low latency

one-to-many!



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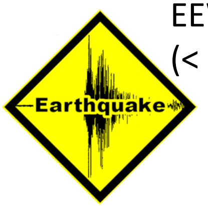
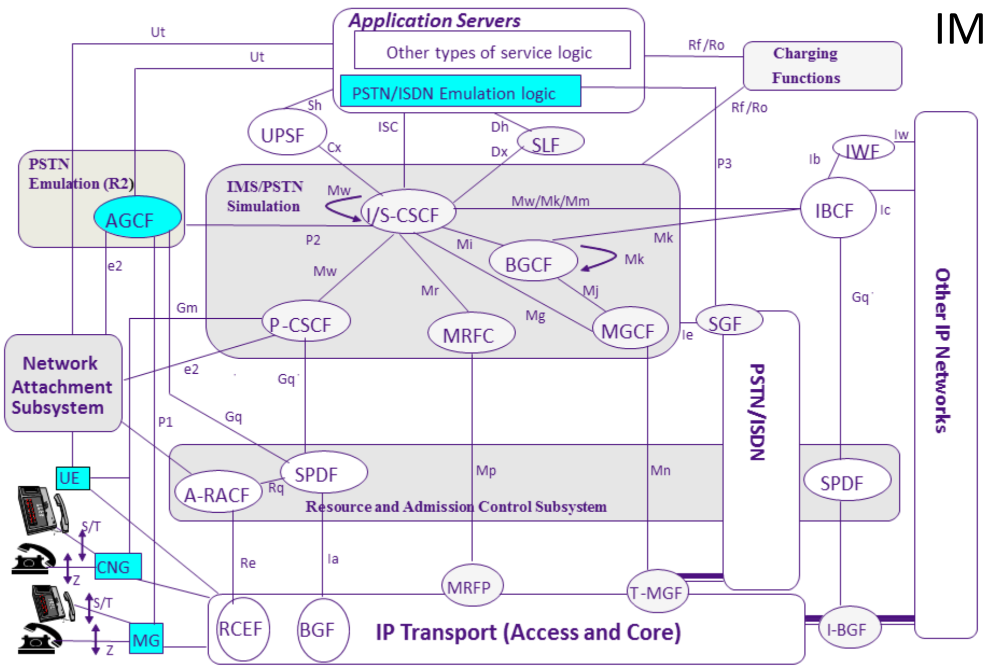


Complexity kills

IMS



Long-range networks

FEATURE	LTE Rel 13	Combined Narrow Band (NB) and Spread Spectrum (SS) (Semtech)	Cooperative Ultra Narrow Band (Sigfox)	Narrow Band M2M Clean Slate (Huawei/ Neul)
Bandwidth	1.4 MHz	400 Hz to 12.8 KHz NB and 200 KHz SS UL / 3.2 KHz to 12.8 KHz DL	160 Hz UL / 600 Hz DL	2 or 3.75 KHz UL / 15 KHz DL per channel
UL Data Rate	TBD	122 bps – 7.8 Kbps	160 bps / 600 bps	200 bps to 45 Kbps
Range / MCL	155.7 dB (24 dBm Tx Pwr)	164 dB (20 dBm TX Pwr)	164 dB (24 dBm Tx Pwr)	162 dB (24 dBm Tx Pwr)
Broadcast/Multicast	Yes	Yes	No	No?
Duplex	Full/Half Duplex (FDD)	Full-Duplex	Full Duplex	Full-duplex
Synchronization	Yes	Yes	No	Yes

IoT requirements

Application	Range	Mo-bility	Device characteristics	Service characteristics	Suitable networks
• Connected car • Fleet management • Remote health monitoring	~1000m	Yes	Rechargeable battery	Managed service, highly secure	• Cellular • Satellite
• Smart metering • Parking meter	~1000m	No	Low rate, low power, low cost	Managed service	• Cellular • Dedicated network
• Hospital asset tracking • Warehouse logistics	~100m	Yes	Low rate, low power, low cost	Enterprise-deployed	• WiFi • RFID
• Industrial automation • Home automation	~10m	No	Low rate, low power, low cost	Subscription-free	• Zwave • Zigbee • Wifi • Powerline
• Personal activity • Local object tracking • Point of sale	~1m	No	Low rate, low power, low cost	Subscription-free	• Bluetooth • NFC

Wide-area Wireless Communication Challenges for the Internet of Things
Harpreet S. Dhillon, Howard Huang, Harish Viswanathan

Niche networks persist

short range

ZigBee®

low energy; mesh

Bluetooth®

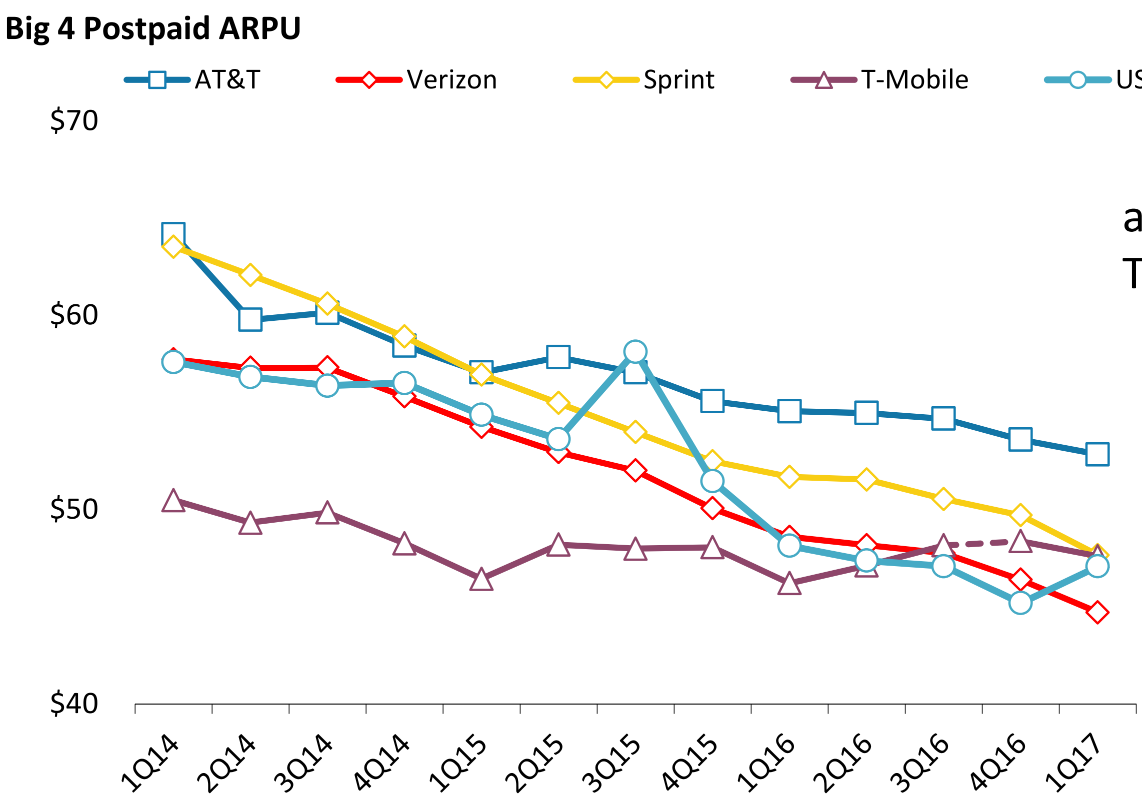
ubiquity; low cost

tries to usurp niche

WiFi™

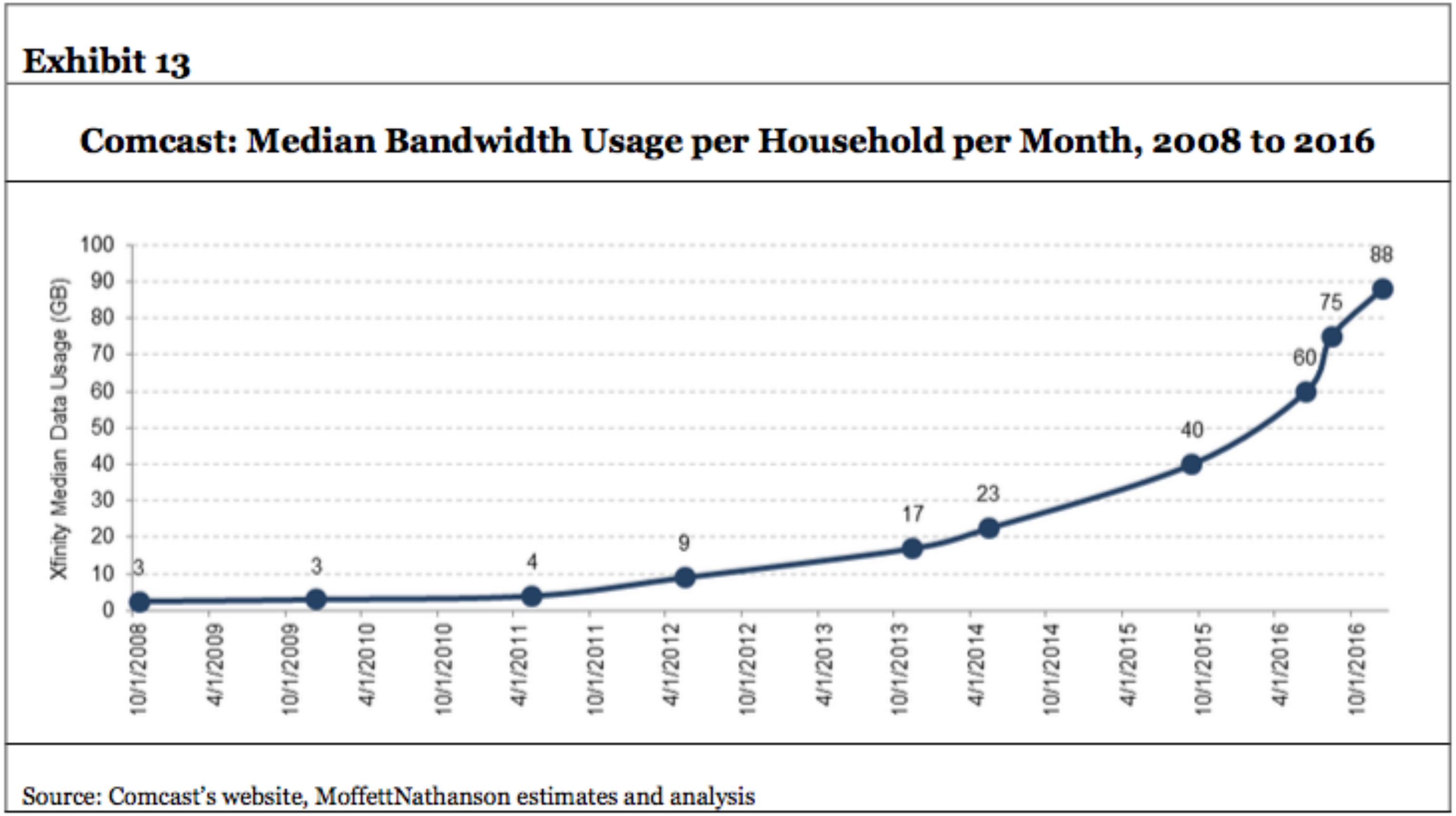
speed; public APs

What's the economic case for 5G?



avg. about 2.1 GB/month
T-Mobile: 10 GB tethering

Cord-cutting for broadband?



How can 5G be cheaper by GB?

Backhaul is major cost factor

- "Backhaul costs represent almost 6% … of a wireless carrier total operating expenses (OPEX) and 30% of total network costs."

Re-use existing fiber to residential users

- Requires cooperation of cable/FTTH provider

Reduce license cost for spectrum → unlicensed, mmWave

- first step: LTE-U

Table 5. Wireless Network Cost Breakdown (OPEX and Headcount CAPEX)

Subcomponents	Carrier A	Carrier B	Carrier C	Carrier D	Average of All Carriers
Strategy and Support	13	8	10	19	14%
Network infrastructure rent	36	45	33	37	39%
Transmission	6	5	13	8	7%
Core Network	10	9	13	3	8%
Radio ops & maintenance	11	15	18	14	14 %
Radio deployment	13	8	8	10	10 %
Radio design	10	9	5	8	8 %

Source: Wireless Carriers Benchmarking Study

Spectrum for 5G

Changing spectrum environment

Except at highest frequencies, all new spectrum likely to be shared

- e.g., 3.5 GHz
- in time & space

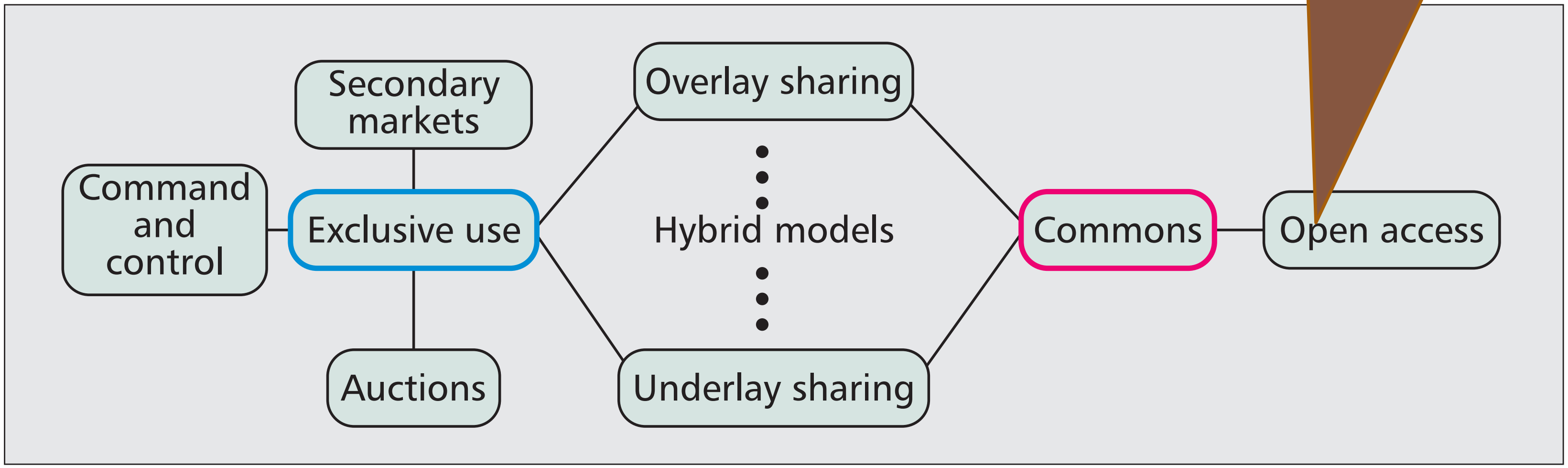
→ need frequency-agile systems that can shift capacity to different bands, quickly

→ few common bands for consulting spectrum database

- **now**: scan, pray & wait
- **5G**: shared band → database

Spectrum sharing

How much politeness & fairness is required?
→ LTE-U & LTE-LAA (license-assisted, listen-before-talk)



Ideal spectrum

Unused or cheap

Av ilable globally ( ) ortant for consum ize)

- rably und sing condi

No r

Propag

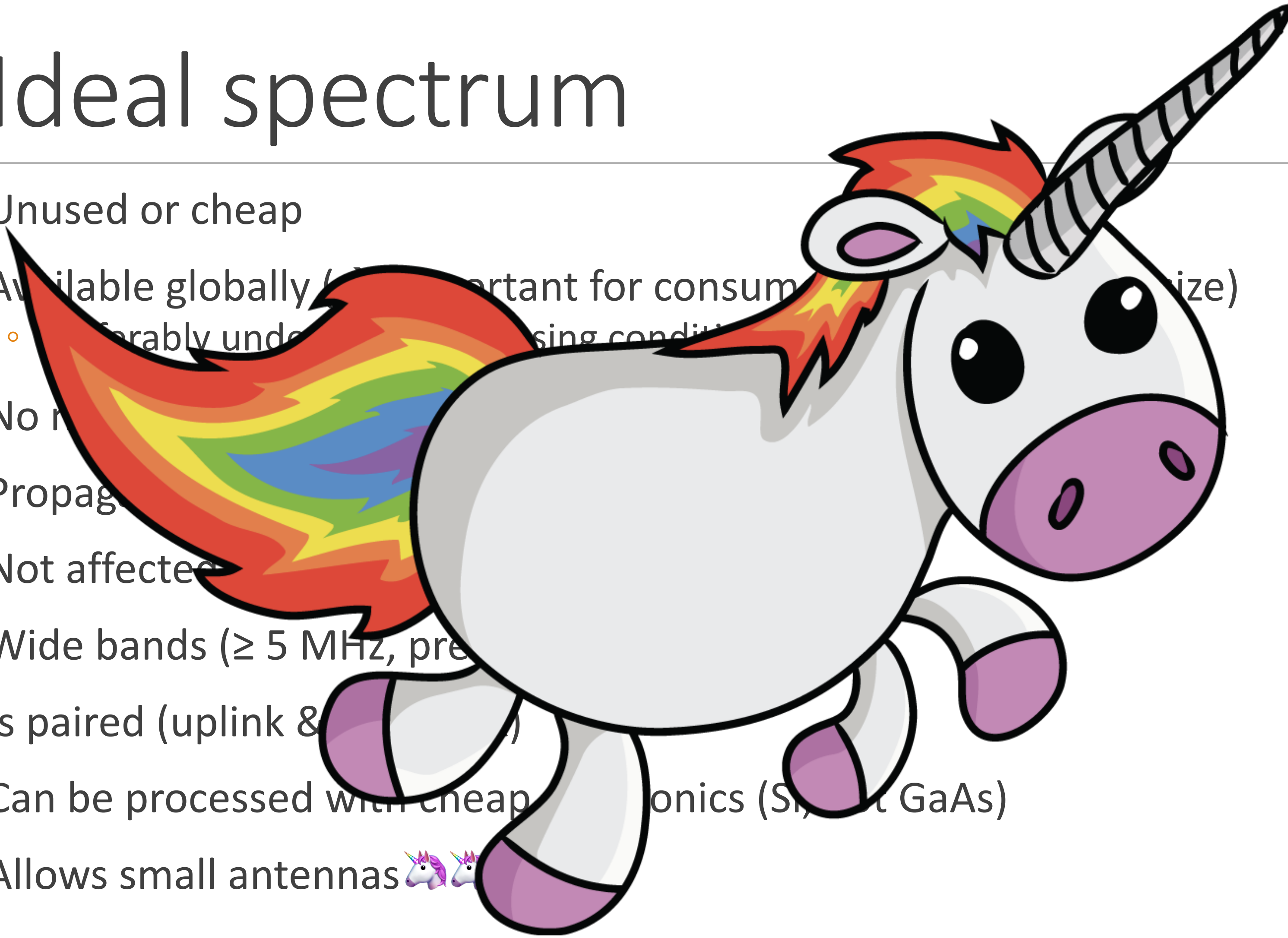
Not affecte

Wide bands (≥ 5 MHz, pre

Is paired (uplink &)

Can be processed w cheap onics (Si, t GaAs)

Allows small antennas 🦄🦄



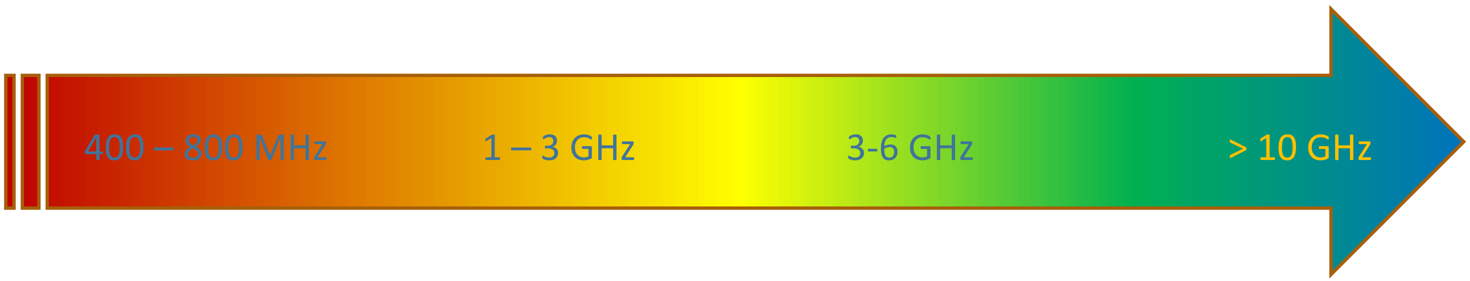
Spectrum co-existence

vs.

"high tower, high power"
(TV, cellular downlink, radar transmitter)

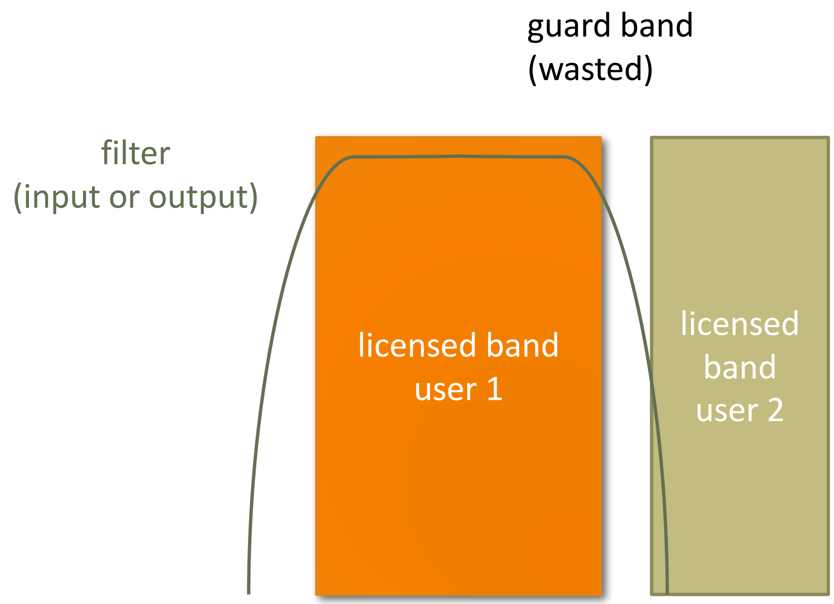
- cellular uplink
- radar receiver
- GPS receiver

Spectrum roles



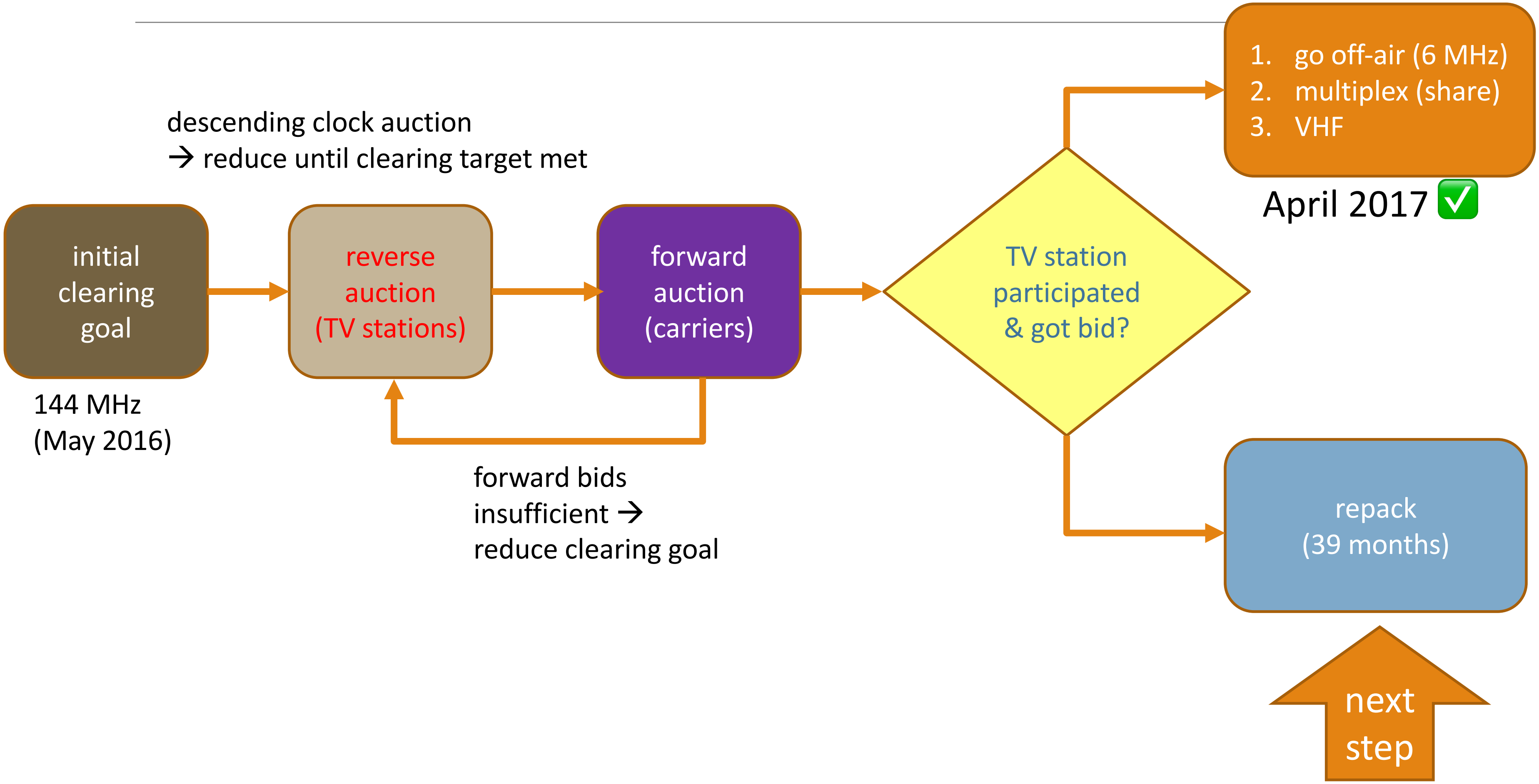
base-level coverage (particularly rural)	urban capacity	indoor & capacity	directional capacity
Digital dividend TV incentive auction	AWS-3	3.5 GHz	mmWave R&O

The filter problem

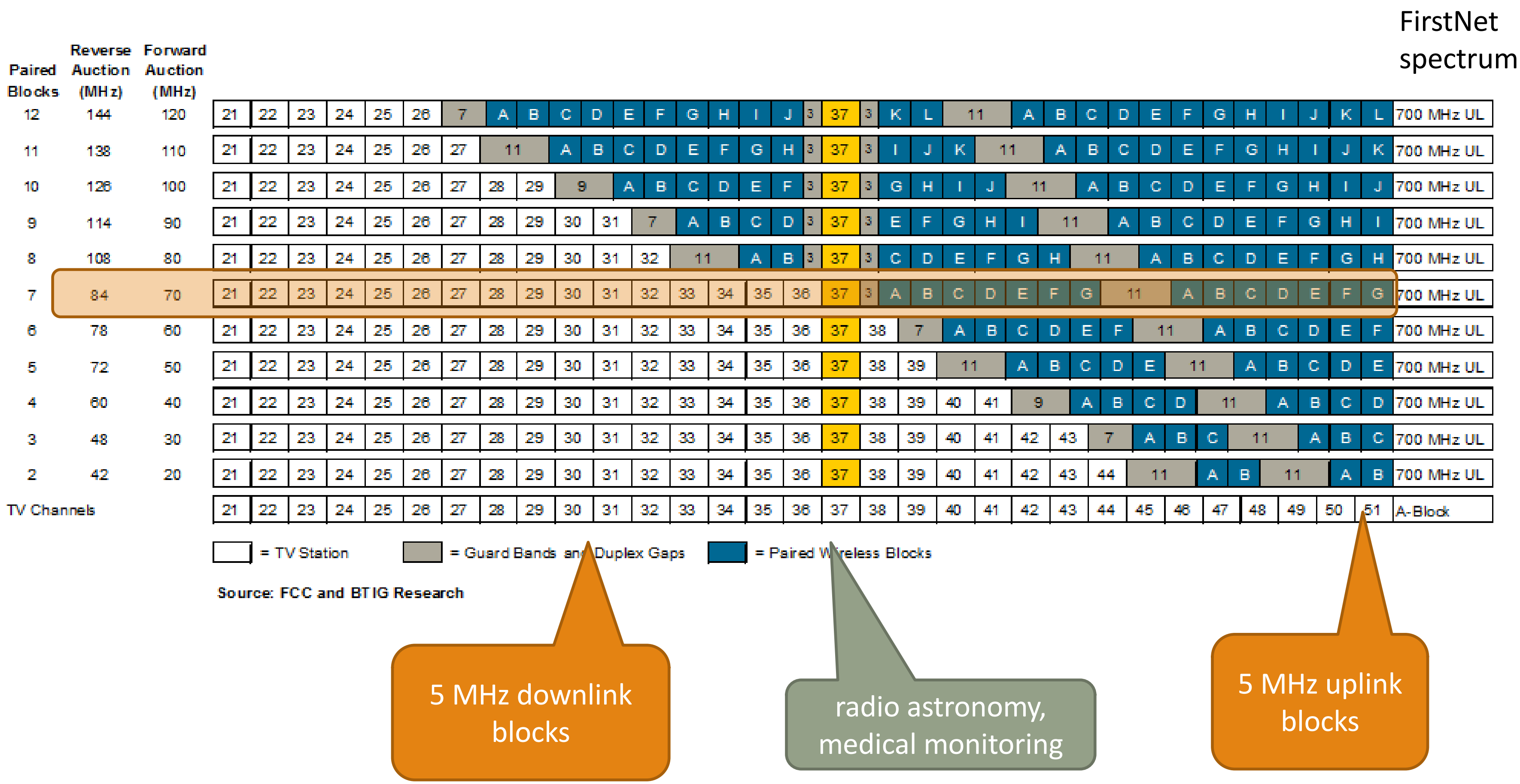


Power imbalance:
- cell downlink: 100 W ERP
- cell uplink: 0.05 – 2 W

TV incentive auction



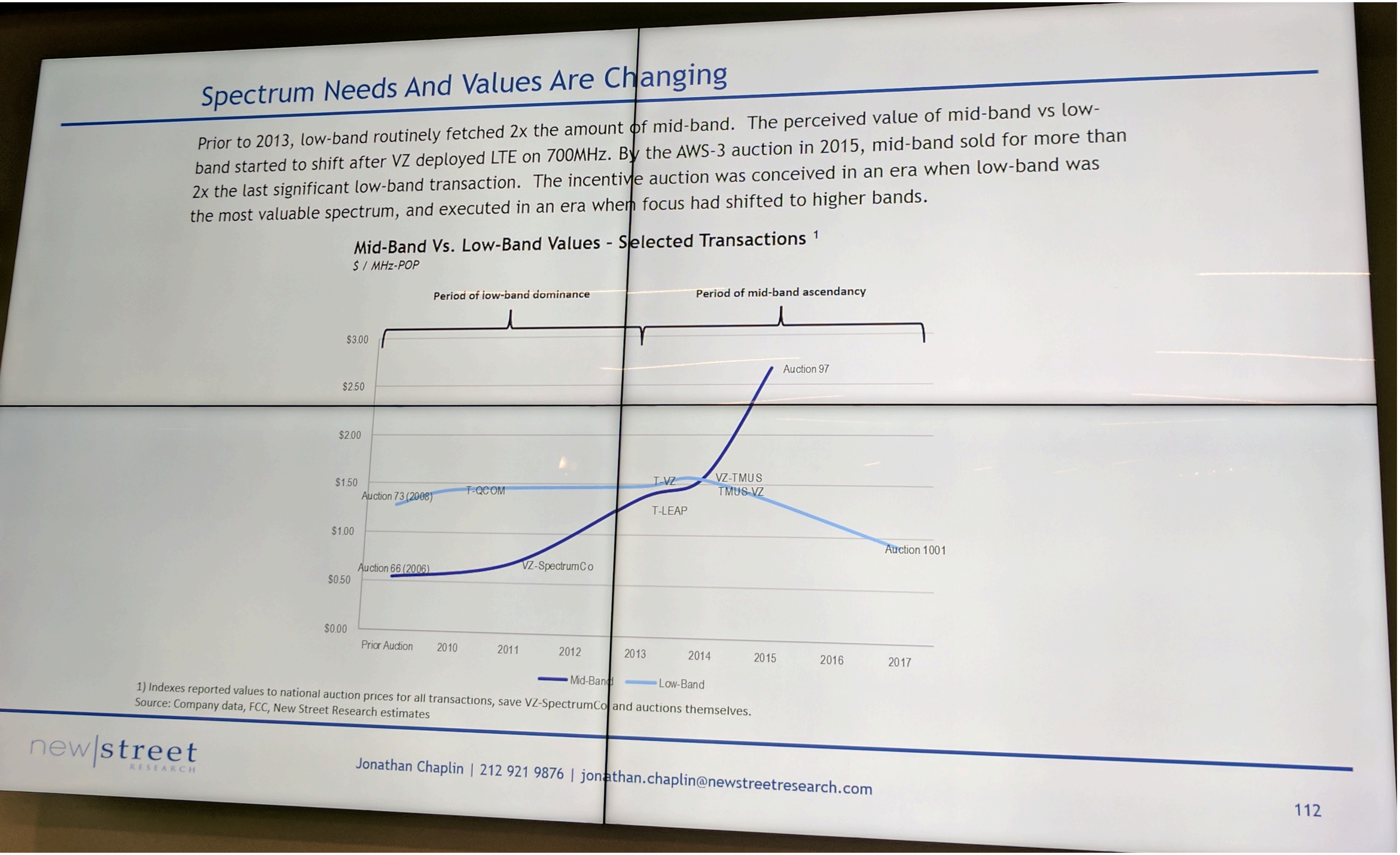
600 MHz incentive auction



Incentive auction facts

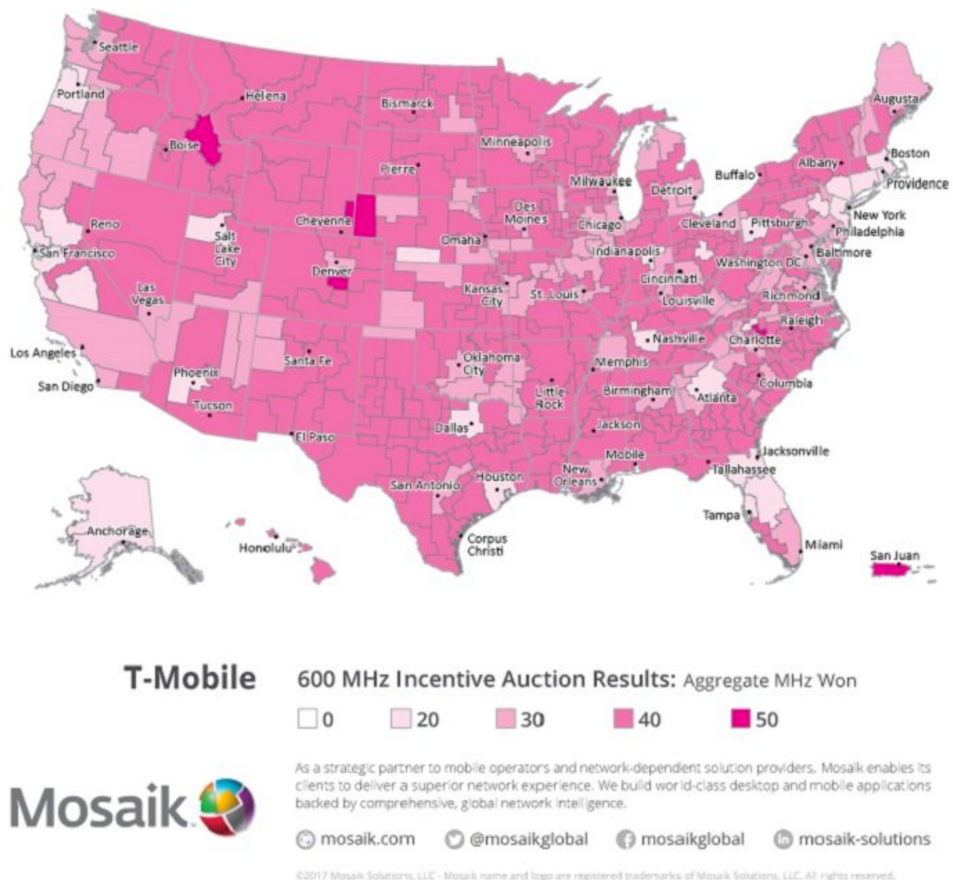
Forward Auction

$19.8 billion	Gross revenues (2nd largest in FCC auction history)
$19.3 billion	Revenues net of requested bidding credits
$7.3 billion	Auction proceeds for federal deficit reduction
70 MHz	Largest amount of licensed low-band spectrum ever made available at auction
14 MHz	Spectrum available for wireless mics and unlicensed use
2,776	License blocks sold (out of total of 2,912 offered)
$1.31	Average price/MHz-pop *sold* in Top 40 PEAs
$.93	Average price/MHz-pop *sold* nationwide



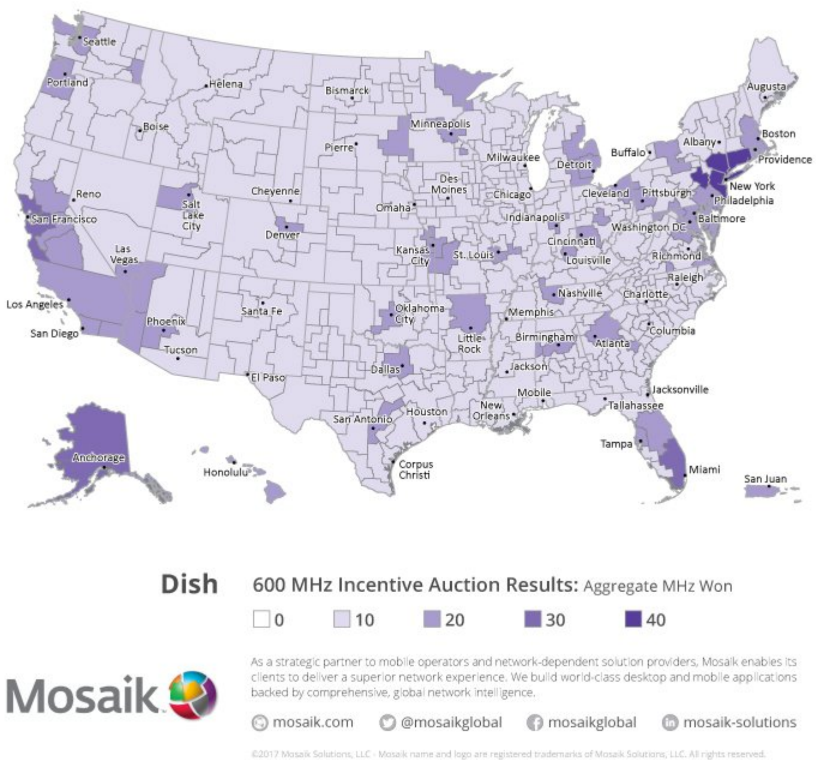
https://law.duke.edu/innovationpolicy/spectrum-incentive-auction/

Forward auction: T-Mobile



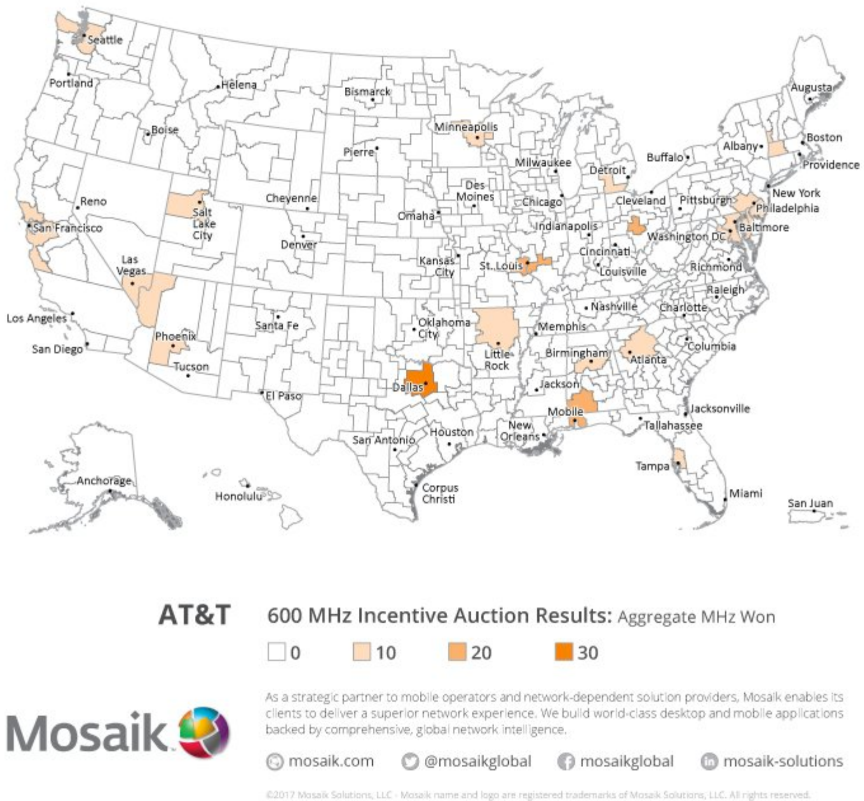
$8B

Forward auction: Dish



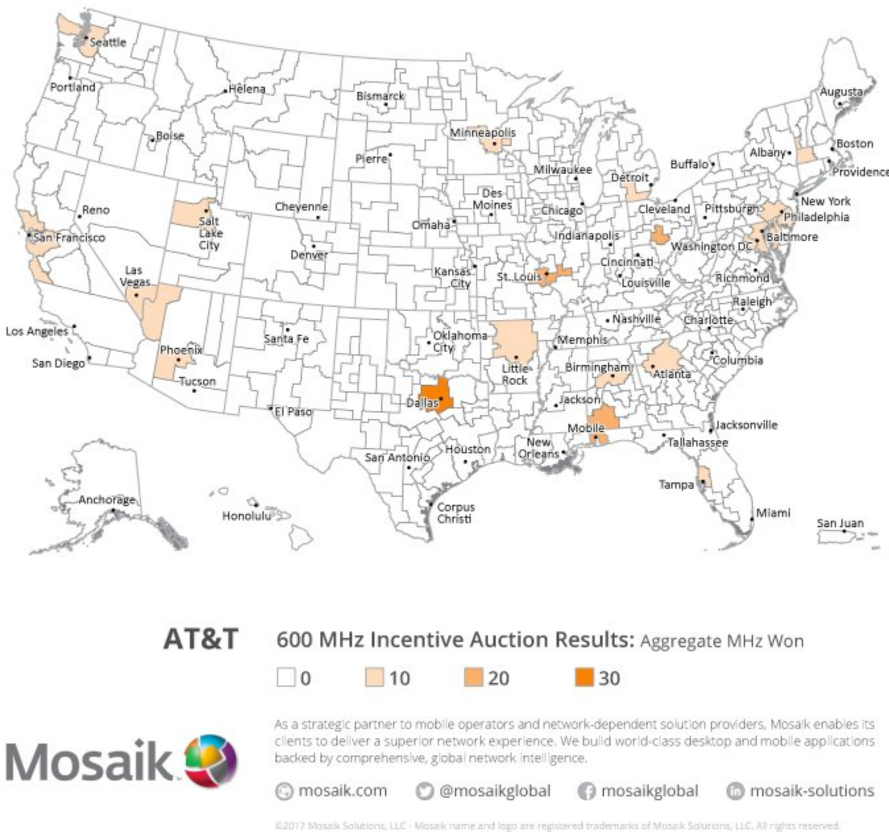
$6.2B
486 licenses

Forward auction: Comcast



$1.7B
145M POPS

Forward auction: AT&T



$1B
18 PEAs
(has 700 MHz spectrum
FirstNet spectrum

TV white spaces (US)

First large-scale spectrum database

But limited use in the US

- number of channels
- power levels
- equipment
- available mostly in rural areas, not urban
- change after incentive auction

Leonia, NJ

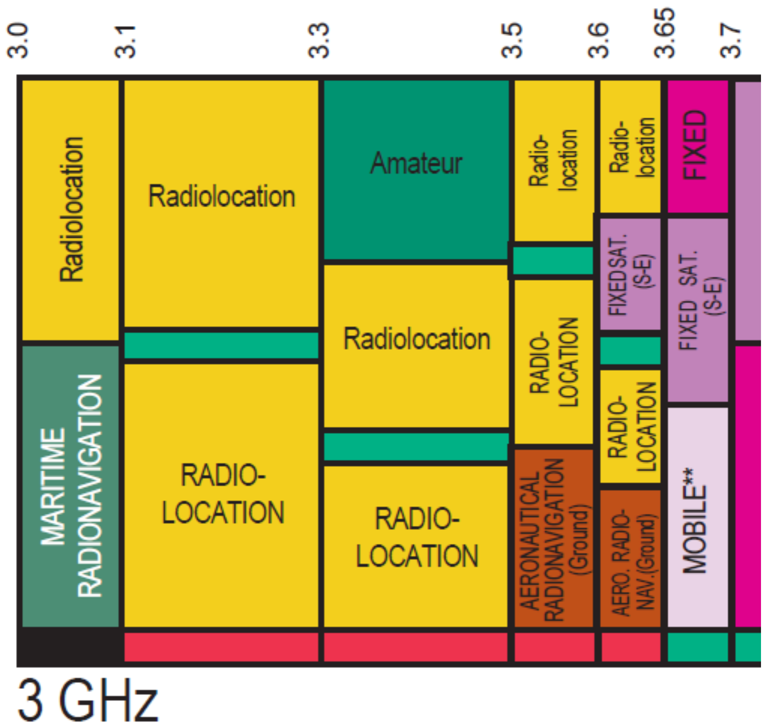
Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)
42	638-644	40

Amherst, MA

Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)
23	524-530	40
24	530-536	100
25	536-542	100
26	542-548	100
27	548-554	40
41	632-638	40
42	638-644	40
44	650-656	40
47	668-674	40
48	674-680	40
50	686-692	40

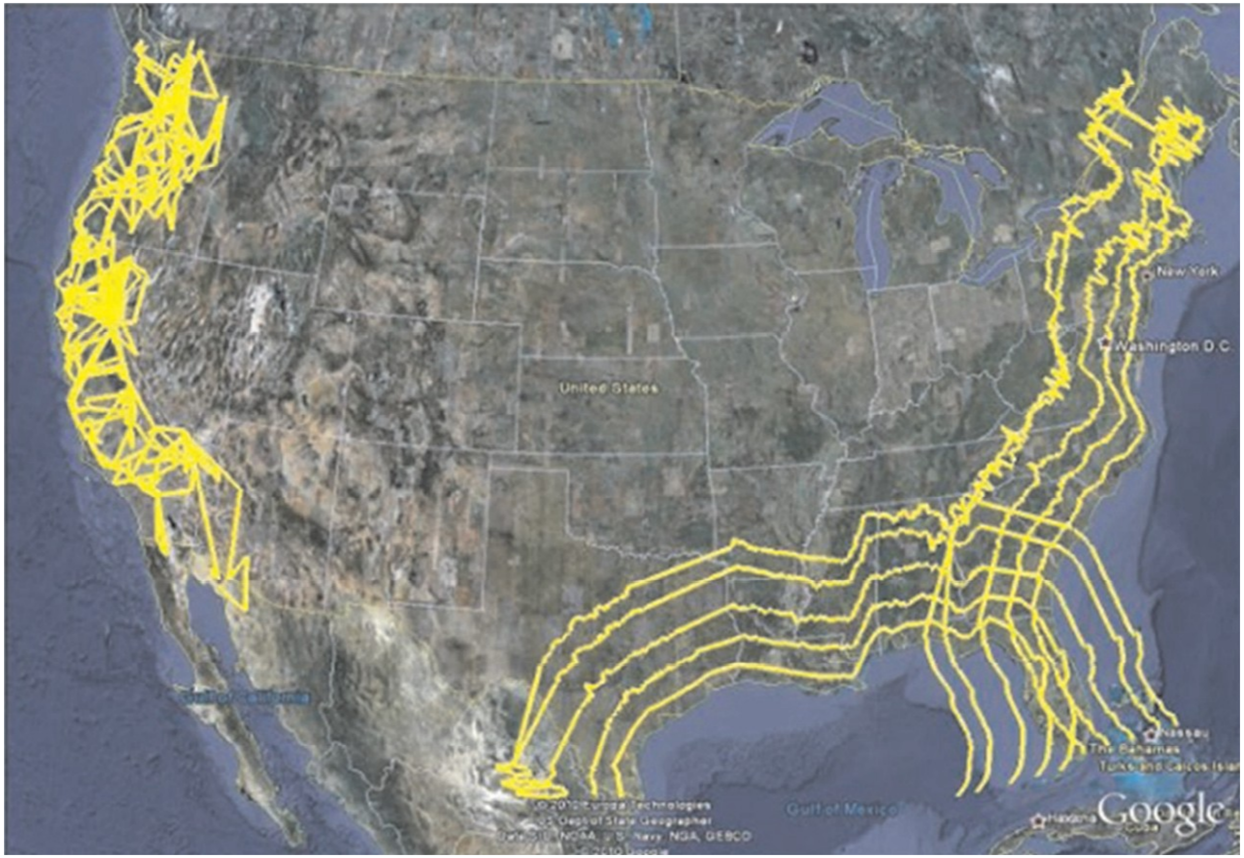
Channel Number	Frequency Range (MHz)	Allowable Antenna Height (meters AGL)
2	54-60	30
7	174-180	30
8	180-186	30
9	186-192	30
13	210-216	30
18	494-500	30
24	530-536	30
25	536-542	30
26	542-548	30

3.5 GHz band



FSS: C Band (3.625–4.200)

Federal Exclusion Zones



3.5 GHz user classes

must not interfere

1

Federal users
Fixed satellite users (FCC)

2

Priority licenses (PAL)
10 MHz channels in 3550-3650

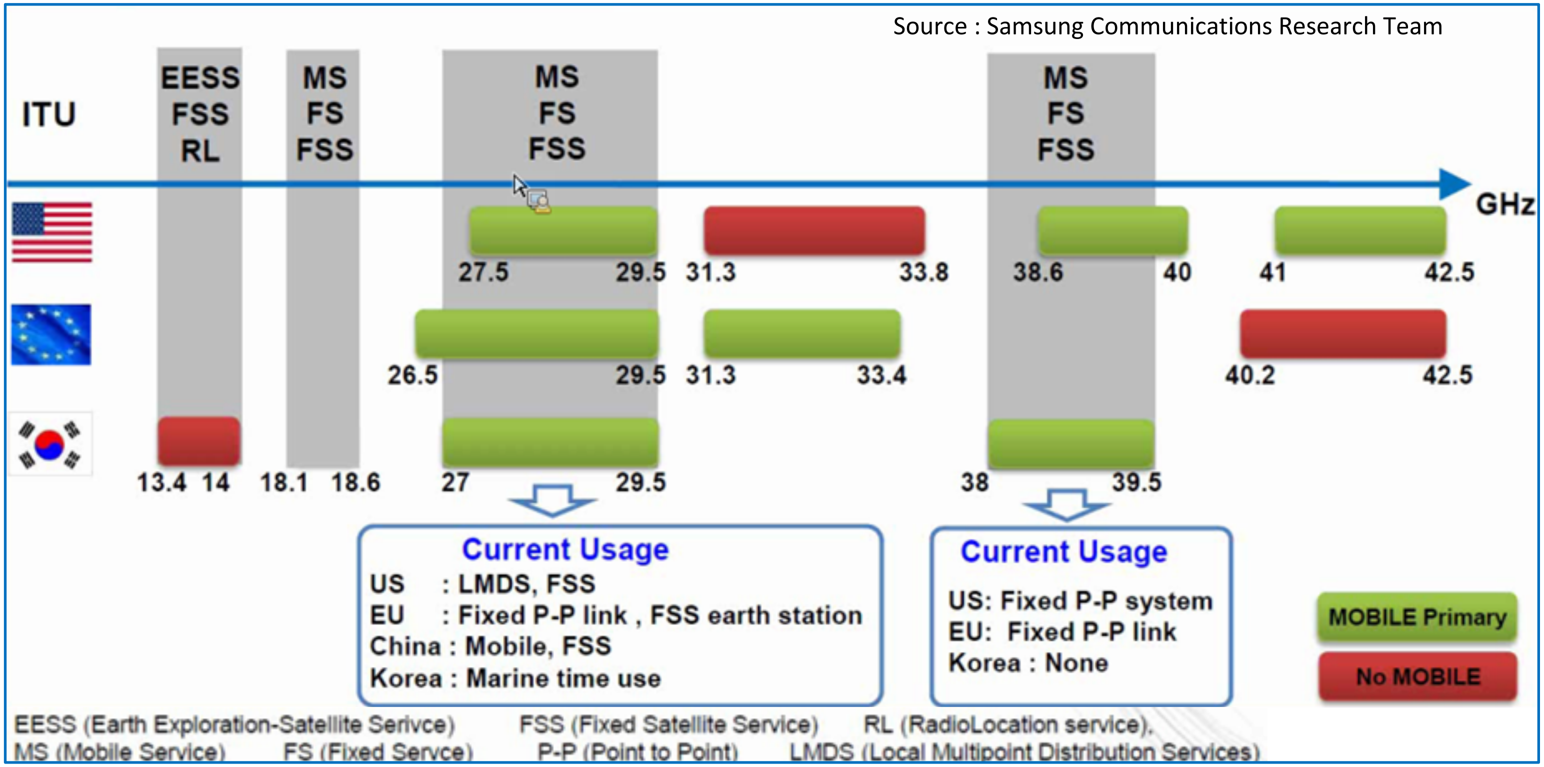
3

General authorized use (GAL)

census tract
≤ 70 MHz
3-year licenses
assigned via SAS

ESC (environmental sensing capability) allows commercial use in coastal and Great Lakes region

30-40 GHz mmW overview



- Note: The Commission's Fixed Microwave (Part 101) and Satellite Communications (Part 25) service rules govern most of US mobile allocations shown above

MMW: Spectrum Frontiers R&O

Core Principles

- Identify substantial spectrum in MMW bands for new services
- Protect incumbent services against interference
- Flexible use: enable market to determine highest valued use
- Overlay auctions where no existing assignments
- Provide spectrum for both licensed and unlicensed use

R&O – 10.85 GHz added for mobile service (July 2016)

- Licensed bands (3.85 GHz): 27.5-28.35 GHz; 37-38.6 GHz; 38.6-40 GHz
- Unlicensed bands (7 GHz): 64-71 GHz

FNPRM – seeks comment on another 18 GHz & above 95 GHz

- 24.25-24.45 GHz; 24.75-25.25 GHz; 31.8-33.4 GHz; 42-42.5 GHz; 47.2-50.2 GHz; 50.4-52.6 GHz; 71-76 GHz; 81-86 GHz; bands above 95 GHz

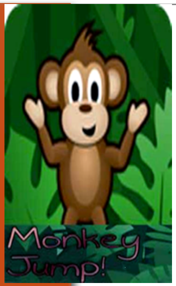
Licensing, operating and regulatory rules

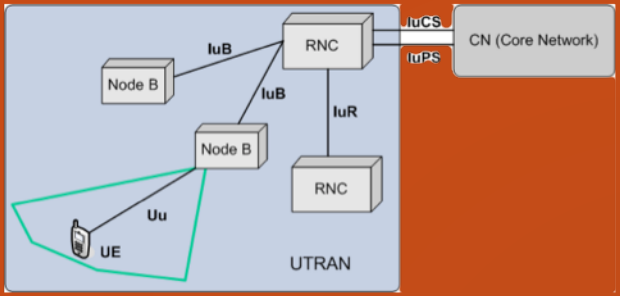
- Part 30: Upper Microwave Flexible Use Service (UMFUS)
- Geographic area licensing, area size, band plan, license term

Network architecture

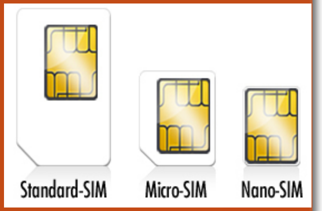
Networks 1G through 4Gish

national carrier

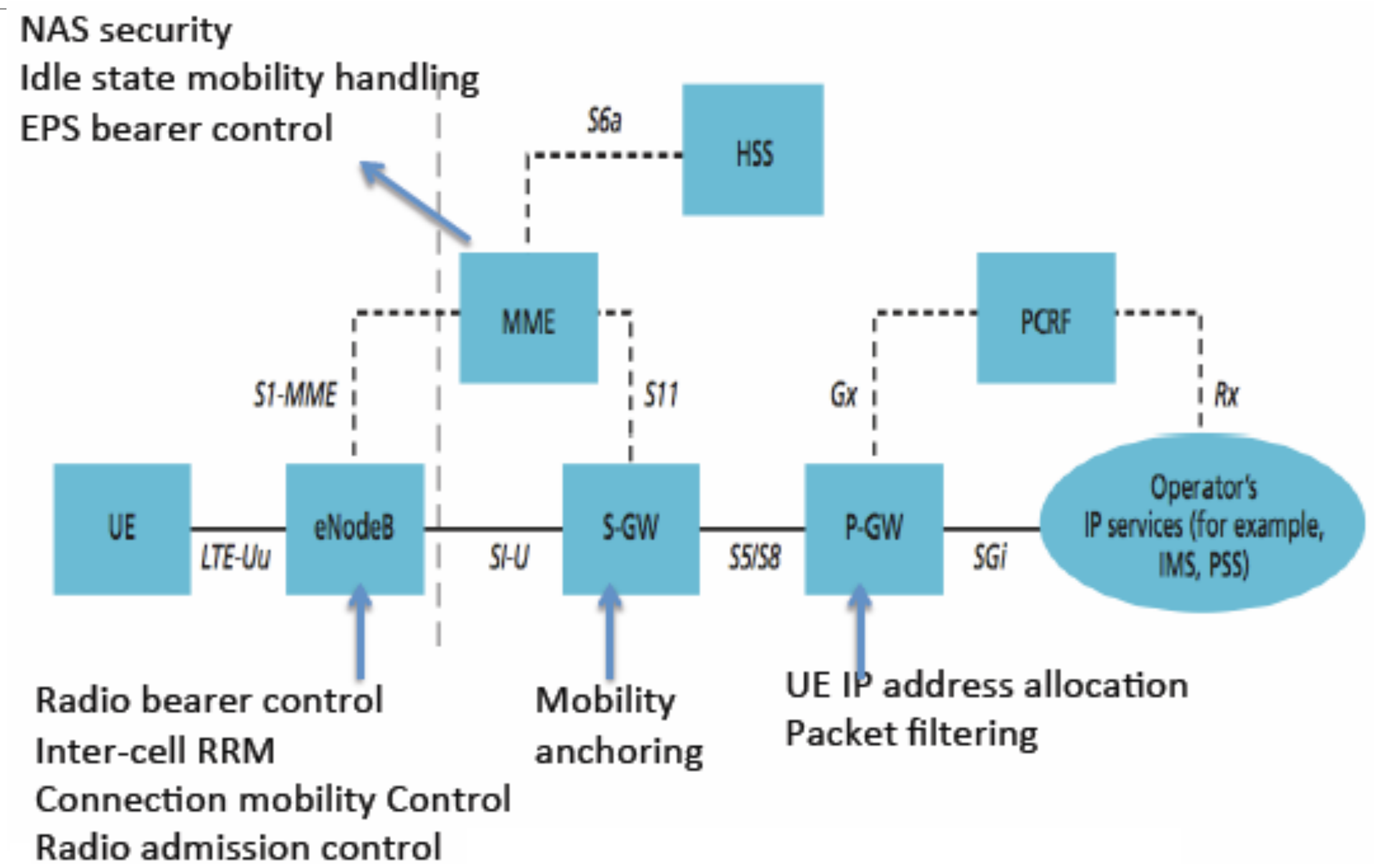




one subscriber,
one phone,
one provider



LTE – one carrier, plus roaming



5G – what exactly is a carrier?

AMERICAN TOWER®

40k towers each (US)

CROWN CASTLE

FiberLight

lightower®

zayo®

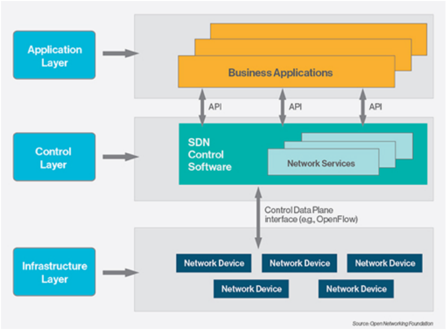
Level3
Cogent

Spectrum
DB

Google play

comcast

LTE-U
802.11n
LTE

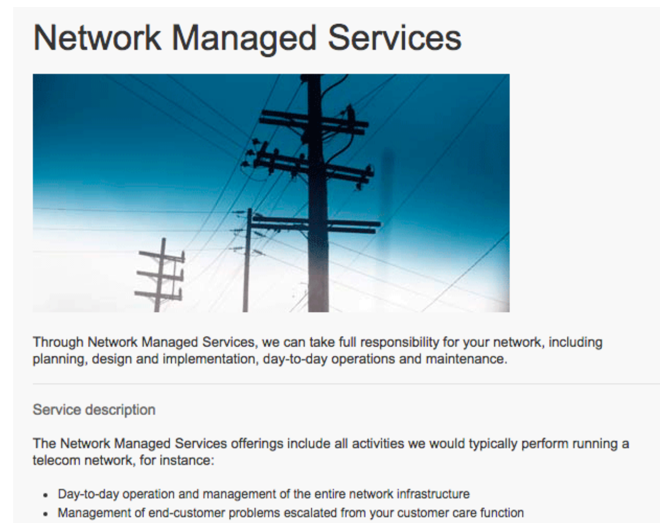


ERICSSON

5G: Carriers as consumer brand

Outside

Inside



Network Managed Services

Through Network Managed Services, we can take full responsibility for your network, including planning, design and implementation, day-to-day operations and maintenance.

Service description

The Network Managed Services offerings include all activities we would typically perform running a telecom network, for instance:

- Day-to-day operation and management of the entire network infrastructure
- Management of end-customer problems escalated from your customer care function

What are carriers good at?

Research?

Software development?

- Who is going to develop those 5G SDN applications?

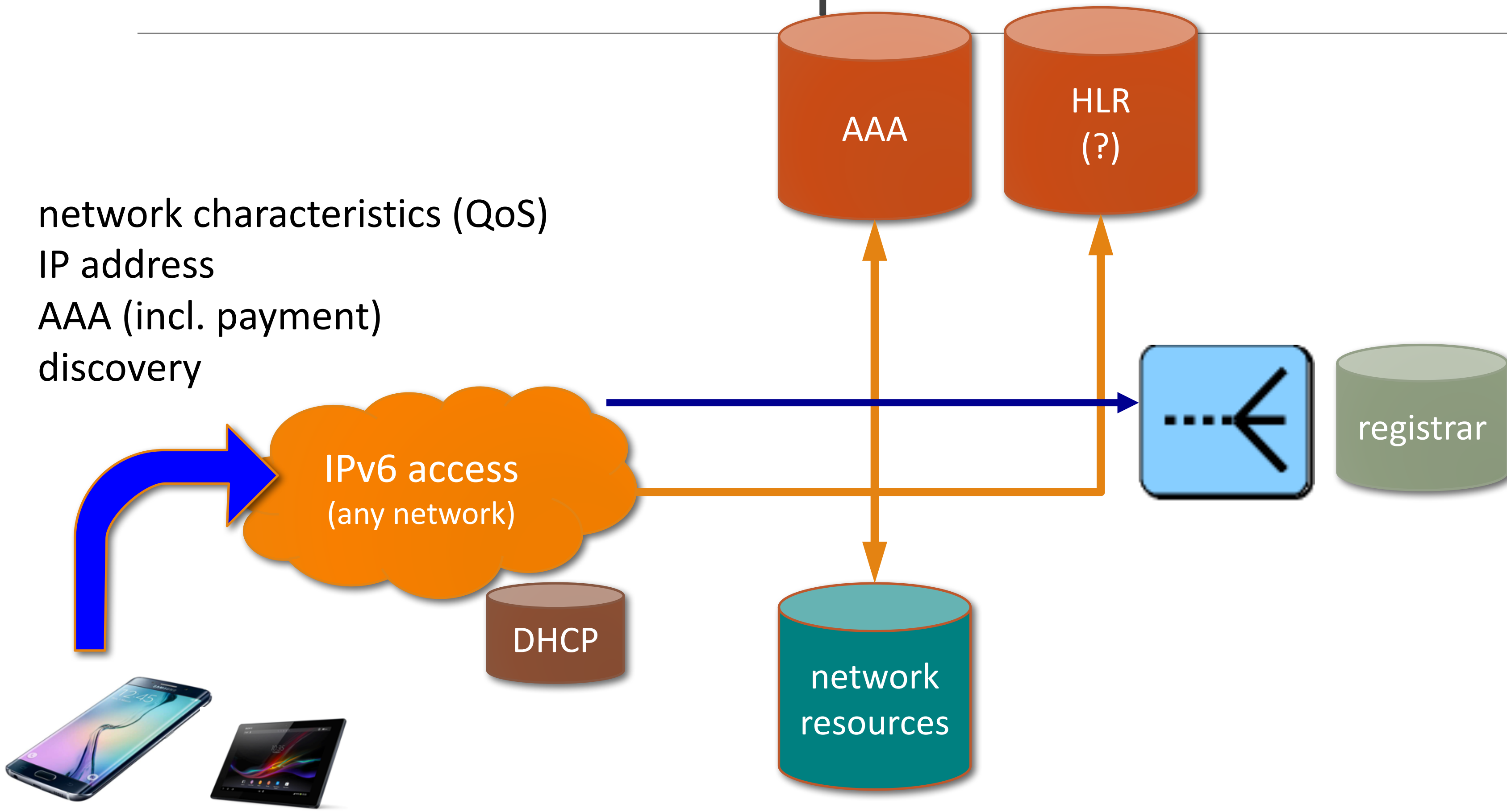
OTT applications?

API-based services?

- Why did Twilio and Tropo offer voice service APIs and not the ILECs?

What's the simplest network?

network characteristics (QoS)
IP address
AAA (incl. payment)
discovery



one subscriber, multiple devices, multiple providers

Where do we need mobility?

likely to have access provider diversity
- what is expected lifetime of IP address?

PMIP and MIP complex
- need to re-create application-layer security at L3

not really needed for HTTP video
- use mTCP?
- or HTTP restart?

maybe not even for real-time media
- registrar for new-call reachability
- application layer (SIP) mobility for mid-call hand-off?

or tunnels, tunnels everywhere?

The law of new networks

"Any new network technology will be justified on (finally) providing QoS"

To succeed, they have to provide good-enough QoS for best effort

- at least with competition

The business model for QoS is difficult

- see bypass toll roads

QoS is usually not accessible to applications

- or not end-to-end

I-495 Express Lanes Endure Big Losses Early On Way To Potential Profit

By: Martin Di Caro
February 20, 2015

PLAY   comments 2

WAMU/Martin Di Caro

The 495 Express Lanes offer a paid respite from the usual Beltway traffic, but fewer drivers than expected are using them.

The private sector firm that operates the 495 Express Lanes along the Beltway in Northern Virginia is down more than $230 million on its investment in the two and a half years since the highway opened, but company officials say toll revenues are beginning to consistently exceed operating costs, a sign the project is winning over commuters in one of the region's most congested corridors.

Transurban, the Australia-based toll road builder that operates high-speed HOT (high-occupancy toll) lanes on I-495 and I-95, has said all along it would take years to turn a profit on its enormous investments in Northern Virginia.

Providing a network API

Currently, applications can detect Wi-Fi vs. cellular

What is the correct API for discovering network properties?

- available options (“BE”, “LBE”, “low latency”)

public int **getType** () Added in API level 1

Reports the type of network to which the info in this `NetworkInfo` pertains.

Returns

one of `TYPE_MOBILE`, `TYPE_WIFI`, `TYPE_WIMAX`, `TYPE_ETHERNET`, `TYPE_BLUETOOTH`, or other types defined by `ConnectivityManager`

NetworkInfo.DetailedState	AUTHENTICATING	Network link established, performing authentication.
NetworkInfo.DetailedState	BLOCKED	Access to this network is blocked.
NetworkInfo.DetailedState	CAPTIVE_PORTAL_CHECK	Checking if network is a captive portal
NetworkInfo.DetailedState	CONNECTED	IP traffic should be available.
NetworkInfo.DetailedState	CONNECTING	Currently setting up data connection.
NetworkInfo.DetailedState	DISCONNECTED	IP traffic not available.
NetworkInfo.DetailedState	DISCONNECTING	Currently tearing down data connection.
NetworkInfo.DetailedState	FAILED	Attempt to connect failed.
NetworkInfo.DetailedState	IDLE	Ready to start data connection setup.
NetworkInfo.DetailedState	OBTAINING_IPADDR	Awaiting response from DHCP server in order to assign IP address information.
NetworkInfo.DetailedState	SCANNING	Searching for an available access point.
NetworkInfo.DetailedState	SUSPENDED	IP traffic is suspended
NetworkInfo.DetailedState	VERIFYING_POOR_LINK	Link has poor connectivity.

cost?
($ or count for bucket?)

predicted performance?

IMS /VoLTE

IMS = It Mostly Speaks
VoLTE = Voice-Only Later than Expected

VoLTE: Taking Carriers Beyond Voice

Mon, 06/06/2011 - 12:43pm

by Maisie Ramsay

Get today's wireless headlines and news - Sign up now!

Project yourself into the future – let's say mid-2012. It's been about a year and a half since Verizon Wireless first launched its LTE network in December 2010, and after a long wait, the company has finally come out with the first smartphone running voice over LTE (VoLTE) technology.

You go out and buy the device, turning it on the second you have it out of the box. One of the first things you notice: The phone's native voice application isn't limited to just voice. It has an option for video calls, and there's also an option to send multimedia messages, along with presence indicators that show when people on your contact list can participate in a video call.

AT&T, Verizon Target VoLTE Interop in 2015, RCS Later

By Doug Mohney / November 04, 2014

AT&T and Verizon have officially declared they are working on Voice over LTE (VoLTE) connections between their respective networks and customers. VoLTE calls between Verizon and AT&T customers "is expected" in 2015, according to a statement from the companies. And, there's also some Rich Communications Services (RCS) news buried in the text.

The announcement comes as three out of four major U.S. carriers promote LTE networks and a number of countries plan to turn up LTE and VoLTE in the next 15 months. "Interoperability among VoLTE service providers in the United States and around the world will create a better and richer mobile experience for customers," declares Verizon's press release.

Vodafone Germany announces VoLTE rollout

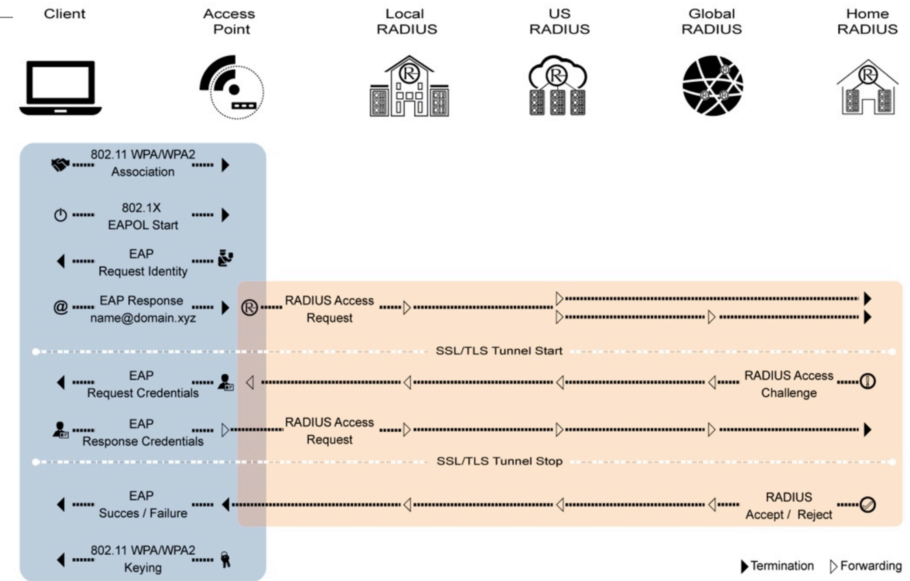
17 Mar 2015

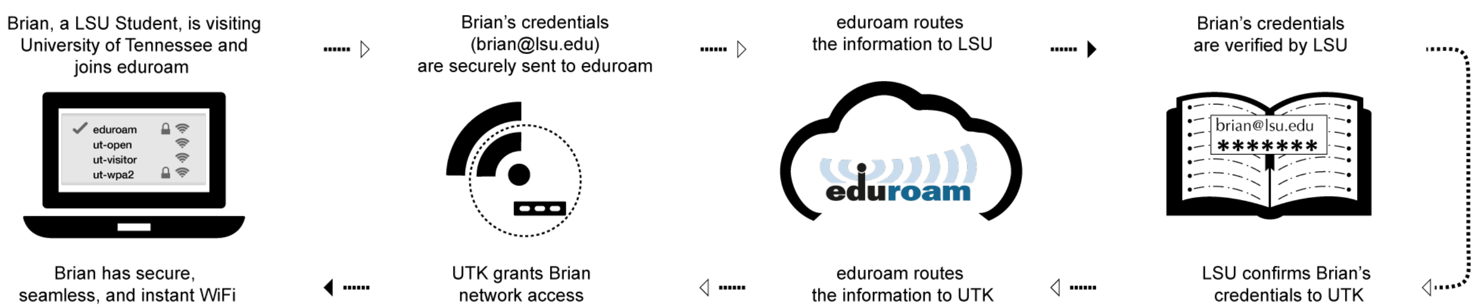
Germany

Vodafone Germany claims it has become the first German operator to initiate the rollout of voice-over-LTE (VoLTE), having demonstrated the first live VoLTE call on its network at the CeBIT 2015 technology fair in Hanover. The UK-owned operator says that the technology offers customers an 'unprecedented voice service and telephony experience', ensuring 'crystal clear voice quality, super-fast call set-up and encrypted phone calls' across its LTE network, which currently covers 70% of Germany. Vodafone revealed that it will soon be launching new LTE smartphones for VoLTE, including handsets from manufacturers such as Samsung, Sony and HTC. The announcement follows reports last week that Vodafone plans to introduce both Wi-Fi calling and VoLTE in the UK this summer, following trials of the technologies in laboratory conditions.

5G prototype: Eduroam

eduroam
Global WiFi Roaming For Academia
an Internet2 NET+ service





Growing-up lessons

Applications surprise

Low cost may beat QoS

Complexity kills

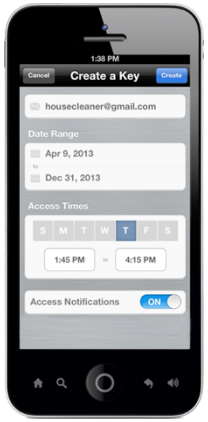
Spectrum is for sharing

5G: 4G++ or opportunity for re-thinking design assumptions

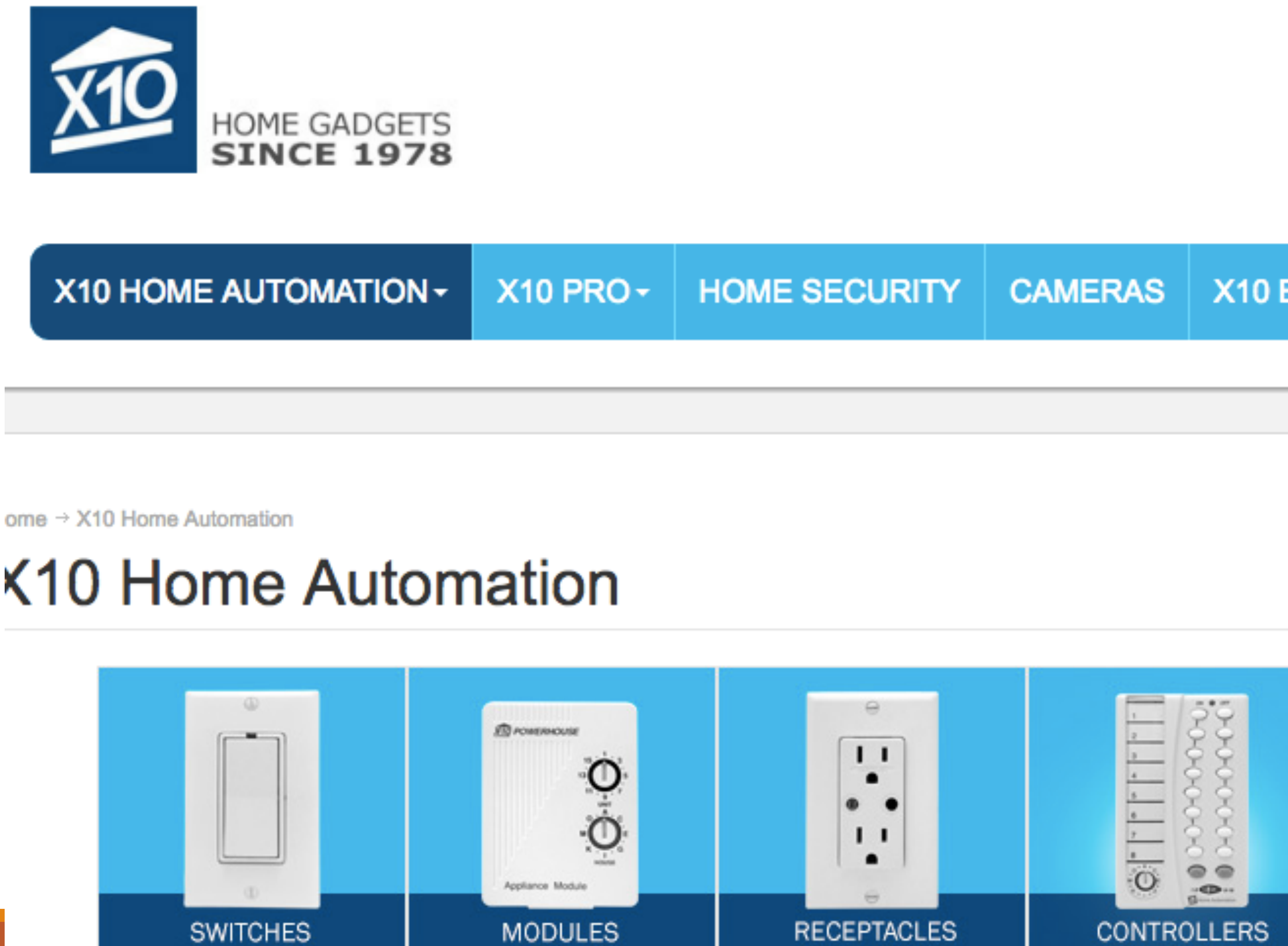
- complexity vs. modularity

IoT

Natural evolution



IoT is not exactly new (1978)



IoT – an idea older than the web (1985)

Peter Lewis (panel discussion 1985)

By connecting devices such as traffic signal control boxes, underground gas station tanks and home refrigerators to supervisory control systems, modems, auto-dialers and cellular phones, we can transmit status of these devices to cell sites, then pipe that data through the Internet and address it to people near and far that need that information. I predict that not only humans, but machines and other things will interactively communicate via the Internet. ***The Internet of Things, or IoT, is the integration of people, processes and technology with connectable devices and sensors to enable remote monitoring, status, manipulation and evaluation of trends of such devices****. When all these technologies and voluminous amounts of Things are interfaced together -- namely, devices/machines, supervisory controllers, cellular and the Internet, there is nothing we cannot connect to and communicate with. What I am calling the Internet of Things will be far reaching.*

From Chetan Sharma Consulting 2016


HUGGIES
Tweet Pee
The first diaper that tells mommy when it's time to change.
Situation
Idea
Design
Results

Towel dispensers

Power over ethernet powered paper towel dispensers

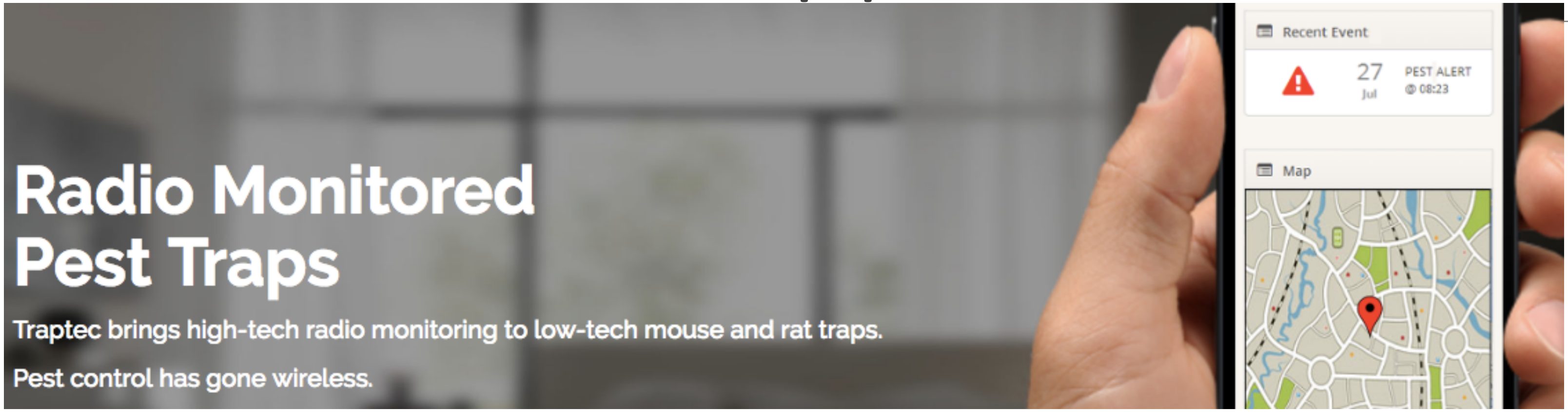
WO 2014028808 A1

ABSTRACT

A system for providing power to a plurality of paper towel dispensers (10) through a power over ethernet (PoE) network (14) and for sensing various operational parameters of the dispensers (10) and communicating those parameters through the network to a central computing device (16). The system includes a Data/Power controller (12) associated with each of the dispensers (10) for providing power (26) to the dispensers (10) and for sending and receiving data (24) between one or more sensors in the dispensers (10) and a central computer device (16).

The IoT has already been used for a range of use cases in facilities management. For example, Coor has worked with a paper towel manufacturer in Sweden to implement automated monitoring of dispensers. Sensors fitted to each dispenser monitor its fill level, and send an alert to the building manager, who can make sure it is refilled before it becomes empty.

The IoT killer app



http://www.traptec.eu/

link.nyc & smart trash cans

GPRS or CDMA
GPS location service

But controlling light switches is still not the best use

Want to turn on the bedroom light? Sure, just pick up your smartphone, enter the unlock code, hit your home screen, find the Hue app, and flick the virtual switch. Suddenly, the smart home has turned a one-push task into a five-click endeavor, leaving Philips in the amusing position of launching a new product, Tap, to effectively replicate the wall switches we always had.

https://techcrunch.com/2014/12/04/the-problem-with-the-internet-of-things/

Where does IoT make sense?

Probably

- home security
- residential & commercial locks
- home medical (recording)
- housekeeping (restroom supplies)
- outdoor lighting
- parking meters
- vending machines

Not so much

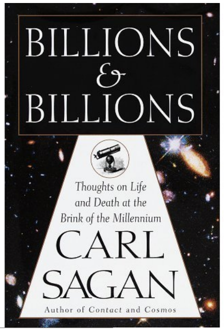
- light switches
- most household appliances
- clothing
- smoke detectors?

not cost-effective, not just useless

Two kinds of IoT devices

< $20	> $50
BlueTooth, ZigBee, proprietary L2	Wi-Fi, LTE-M, LoRa, SIGFOX
connected only via gateway	direct connection to Internet possible
fixed-function: sense or activate	SOC + network module
single chip transceiver + MPU	run (small) Linux stack
only use L2 security	programmable
similar to peripherals	TLS and kin easy

Billions & billions



Ericsson (2010): 50 billion connections in 2020

IBM (2012): 1 trillion by 2015

Gartner (2015): 6.4 billion (2016)

Stringify (2016): 30 billion (2020)

IHS Markit (2016): 30.7 billion (2020)

IDC (2016): 28.1 billion (2020)

3 billion Internet users

Uninteresting – most of these devices are just BlueTooth and Zigbee nodes talking to a gateway

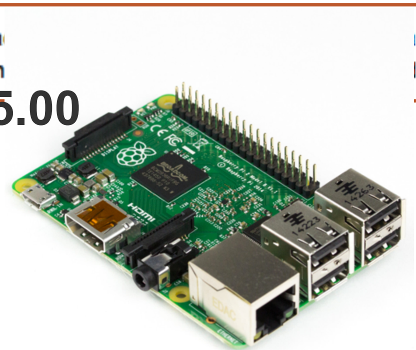
About as useful as counting web pages

Sensor networks may be (tiny) niche

- Most IoT systems will be near power since they'll interact with energy-based systems (lights, motors, vehicles)
- Most IoT systems will **not** be running TinyOS (or similar)
- Protocol processing overhead is unlikely to matter
- Low message volume → cryptography overhead is unlikely to matter
  - exceptions: light switches & 1-function I/O devices → BT/Zigbee
  - Treat like USB devices

In particular, a[…]bout **seven** times as fast as a baseline SPARCstation 20 model 61 — and has substantially more RAM and storage, too. And the Raspberry Pi 2 is **sixteen**[…]l on tasks where all cores can be put to use it's **forty one times** faster.

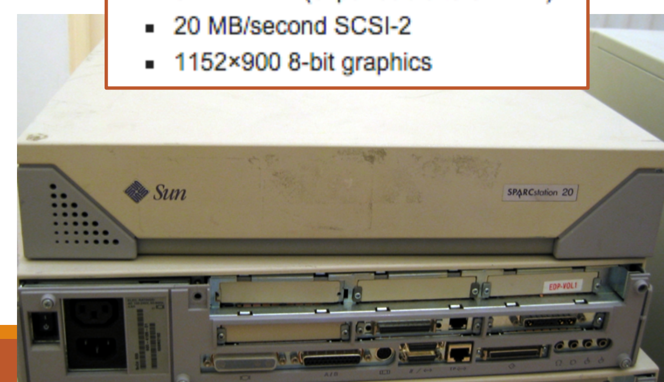
$35.00



- A 900MHz quad-core ARM Cortex-A7
- 1 GB RAM

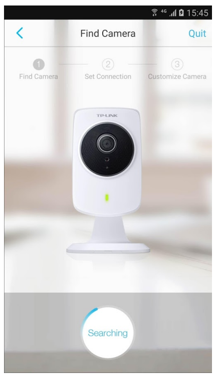
16-41x

- One 60 MHz SuperSPARC CPU
- 1 MB of cache
- 32MB RAM (expandable to 512MB)
- 20 MB/second SCSI-2
- 1152×900 8-bit graphics



http://eschatologist.net/blog/?p=266

Scaling IoT up



one device

apartment building

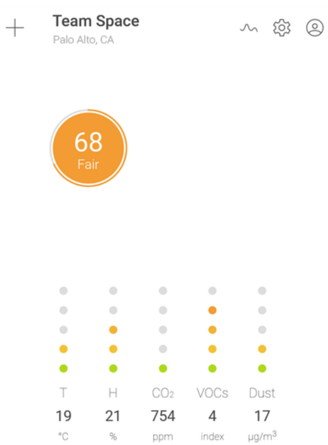
$(10^2 – 10^4)$

city+

$(10^6 – 10^8)$

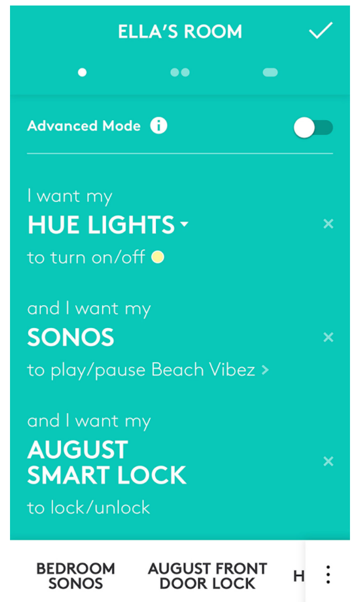
One Thing, one app

Awair



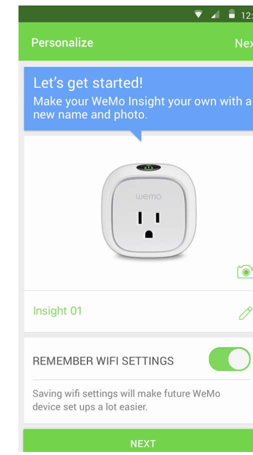
Honeywell

Logitech

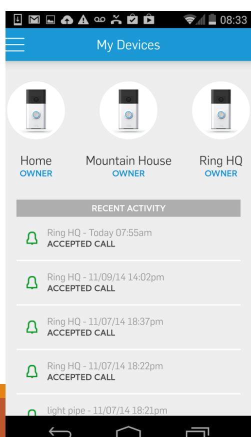


SATIS

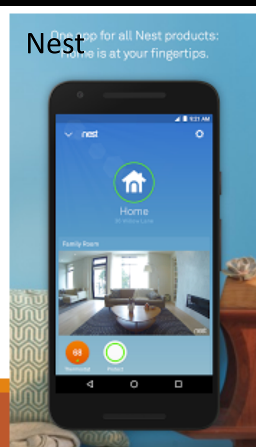
WeMo



Ring

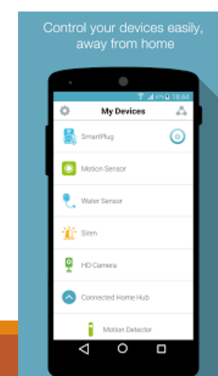


Nest

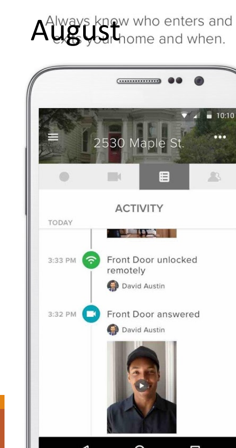


Nespresso

D-link



August



IoT = Internet at scale

Security at scale

- still largely “add password to configuration file”
- identify by IP address

Management at scale

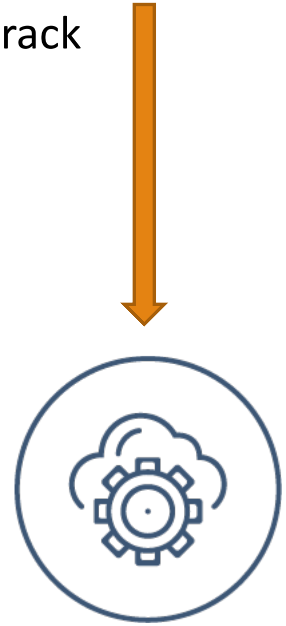
- device-focused
- SNMP, at best
- CLI, at worst
- no performance diagnostics capabilities (“why is this so slow?”)

Naming at scale

- identify by node name

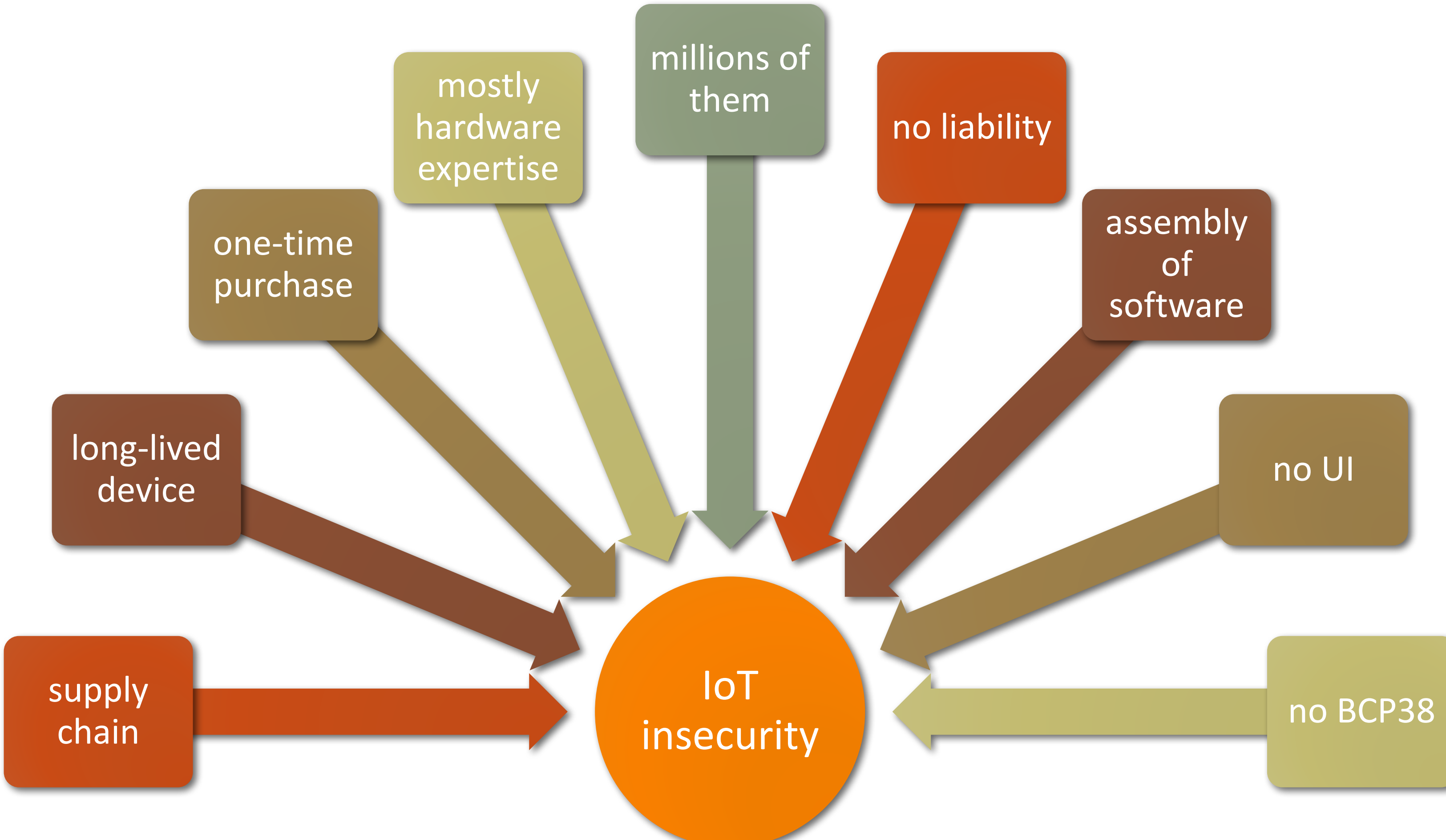
Programming at scale

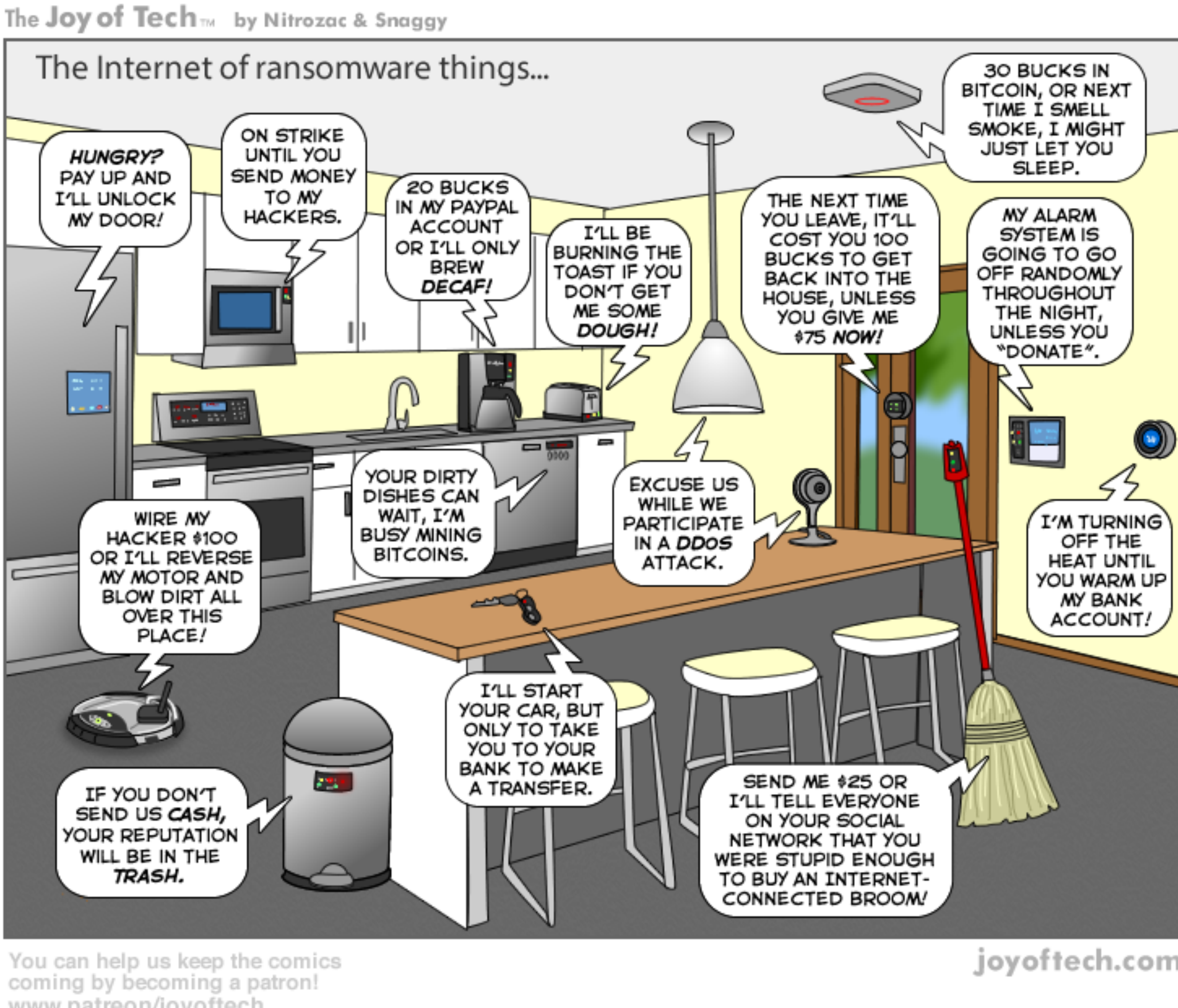
system
& rack



data center

IoT security confluence





The Joy of Tech™ by Nitrozac & Snaggy
The Internet of ransomware things...
HUNGRY? PAY UP AND I'LL UNLOCK MY DOOR!
ON STRIKE UNTIL YOU SEND MONEY TO MY HACKERS.
20 BUCKS IN MY PAYPAL ACCOUNT OR I'LL ONLY BREW DECAF!
I'LL BE BURNING THE TOAST IF YOU DON'T GET ME SOME DOUGH!
THE NEXT TIME YOU LEAVE, IT'LL COST YOU 100 BUCKS TO GET BACK INTO THE HOUSE, UNLESS YOU GIVE ME $75 NOW!
30 BUCKS IN BITCOIN, OR NEXT TIME I SMELL SMOKE, I MIGHT JUST LET YOU SLEEP.
MY ALARM SYSTEM IS GOING TO GO OFF RANDOMLY THROUGHOUT THE NIGHT, UNLESS YOU "DONATE".
WIRE MY HACKER $100 OR I'LL REVERSE MY MOTOR AND BLOW DIRT ALL OVER THIS PLACE!
YOUR DIRTY DISHES CAN WAIT, I'M BUSY MINING BITCOINS.
EXCUSE US WHILE WE PARTICIPATE IN A DDOS ATTACK.
I'M TURNING OFF THE HEAT UNTIL YOU WARM UP MY BANK ACCOUNT!
I'LL START YOUR CAR, BUT ONLY TO TAKE YOU TO YOUR BANK TO MAKE A TRANSFER.
IF YOU DON'T SEND US CASH, YOUR REPUTATION WILL BE IN THE TRASH.
SEND ME $25 OR I'LL TELL EVERYONE ON YOUR SOCIAL NETWORK THAT YOU WERE STUPID ENOUGH TO BUY AN INTERNET-CONNECTED BROOM!
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Summary

Unlike 3G → 4G, 5G is mostly about capacity, not features or per-user speed

Boring is better → reduce network OpEx (and CapEx)

IoT security is exposing almost all the security deficiencies of the Internet eco system

- "thoughts and prayers" approach
- continuing to do the same thing for the next 5 years and hoping for better results is not a strategy

Start thinking beyond stove pipes of applications and home automation

→ engineering large scale systems x 10

Mobile Evolution to 5G

Business drivers and Technology enablers for 2020 networks

Dirk Wolter, Managing Director, Mobile Architecture, APAC
diwolter@cisco.com

April, 2015

Introduction: The Evolution of the Internet

Connectivity

Digitize Access to Information

- Email
- Web Browser
- Search

Networked Economy

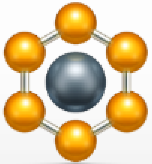
Digitize Business Process

- E-commerce
- Digital Supply Chain
- Collaboration

Immersive Experiences

Digitize Interactions (Business & Social)

- Social
- Mobility
- Cloud
- Video



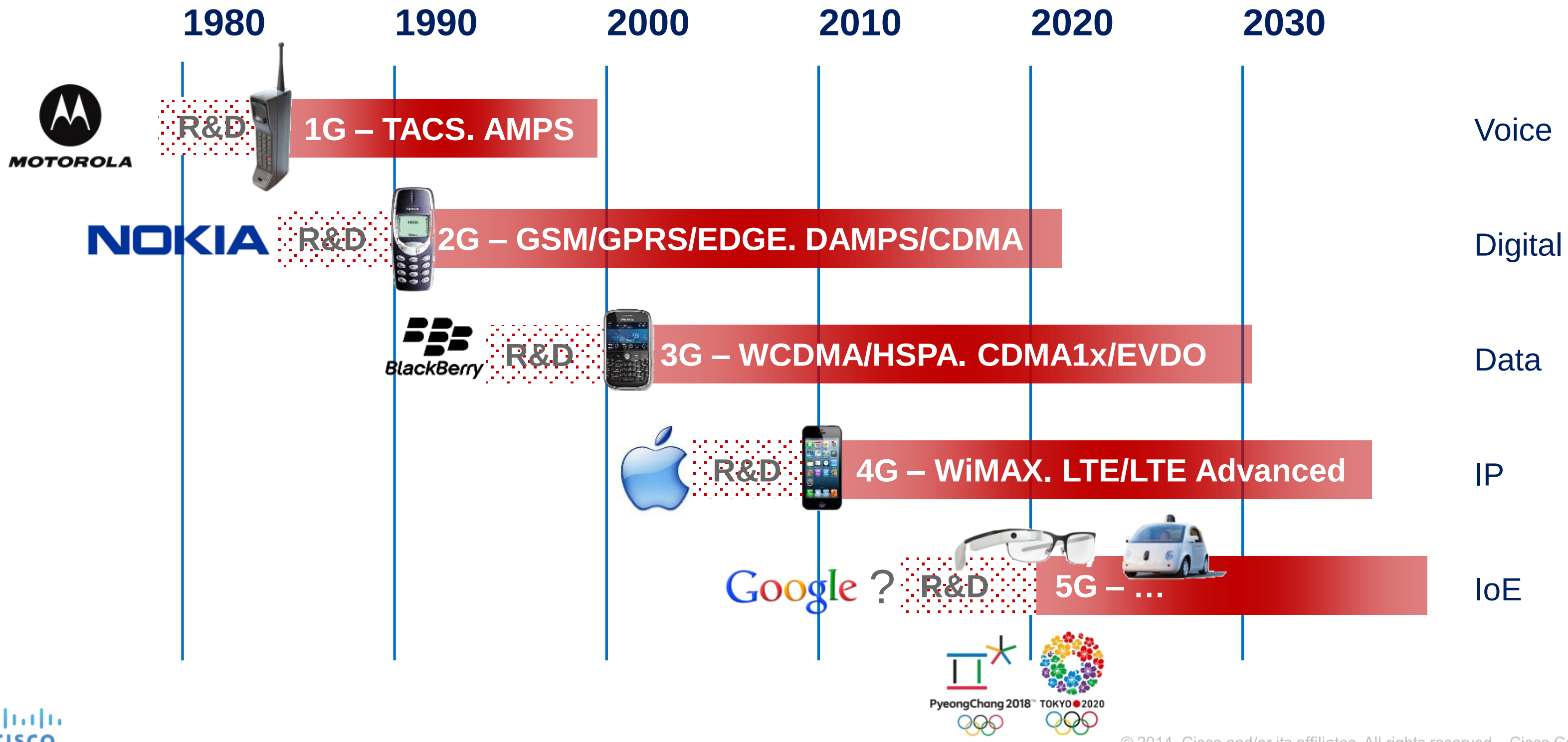
Internet of Everything

Digitize the World

Connecting:
- People
- Process
- Data
- Things

cisco

Introduction: The Evolution of Mobile Technology



Introduction: Business Transitions

New Business Models

- Flexible, usage-based pricing
- Direct, In-direct and Pass through
- IoT/IoE

New Competitors

- Global market reach over the top (OTT)
- Reduced barriers to entry
- Accelerating pace of innovation

New Financials

- Faster RoI
- Predictable OpEx
- Start-up innovation
- Agile Dev-ops

Strategic Options: 1. Smart Utility 2. Platform provider/enabler 3. Diversified player

5G 2020 Vision

- Services
  - Ubiquitous bandwidth (no more cell edge)
  - HD video everywhere (up and down)
  - Internet of Everything (M2M, M2P & P2P)
  - Sensing, Presence and Ad-hoc networking
  - Web eco-system of Apps and Services

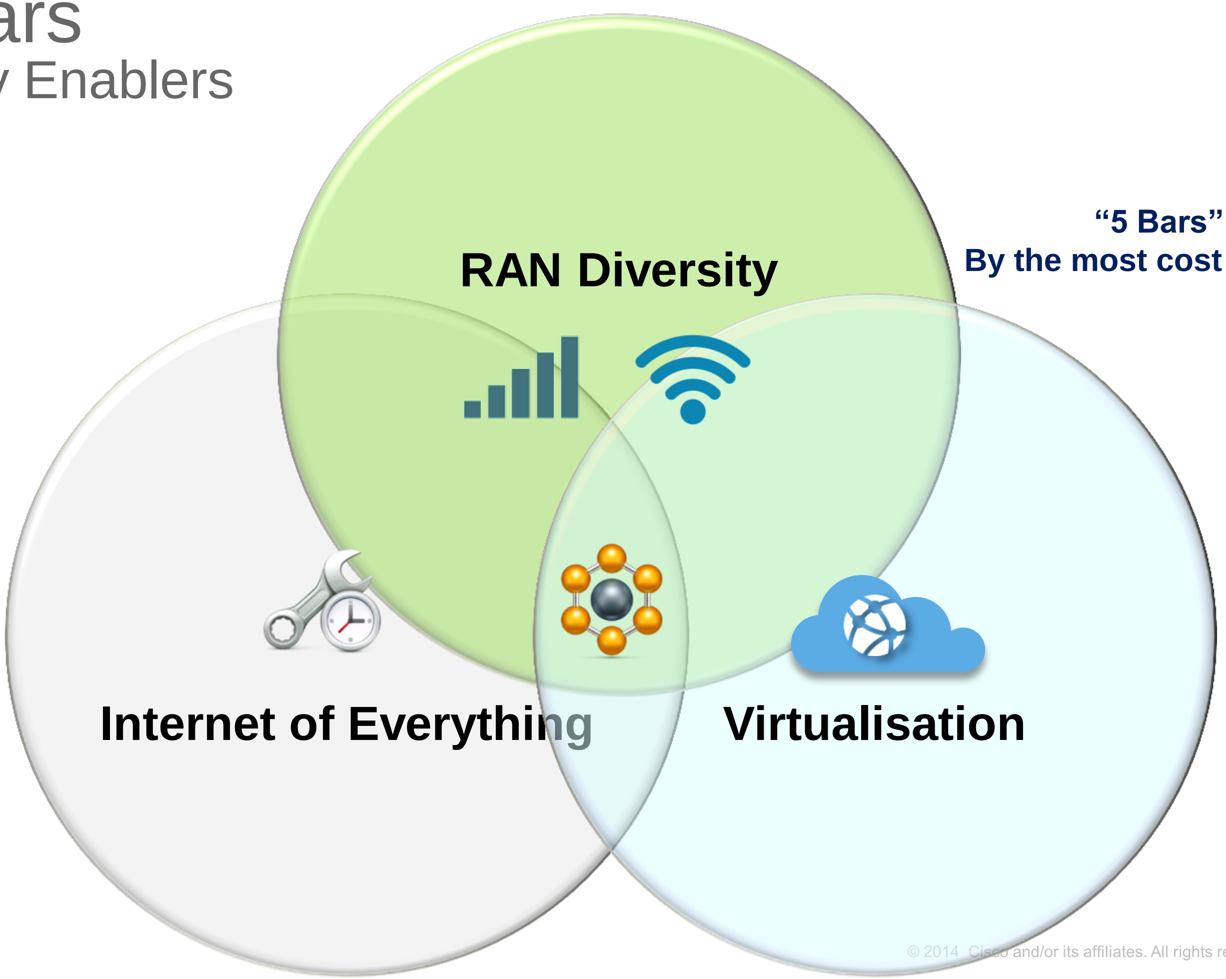
- Technical Requirements

1. Higher System Capacity
2. High Data Rates
3. Lower Latency
4. Mass Connectivity
5. Energy Efficient
6. More Agile

- 1000x capacity/km2
- 10-100x current 4G rates
- Below 1ms
- 100x connected devices
- 10x Network and Device power savings
- 10x faster time-to-market

5G: Pillars
Technology Enablers

"5 Bars" Service
By the most cost effective access



Provide Business Solutions

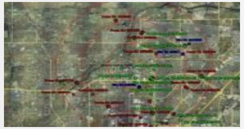
Lower TCO
Increase Agility

Internet of Everything Service Providers

Connections | Impacts

M2M

- Cars/Trucks
- Roads
- Appliances sensors
- Digital billboards
- Vending
- Inventory (RFID)
- Office facilities



Remote Site Monitoring Service

M2M Commerce

Intelligent Diagnostics

Targeted Advertising

M2P

- Intelligent GPS
- Home security devices
- Home energy devices
- Automated customer notifications
- Auto-translation
- Sponsored data
- Connected Life

Personalized Traffic report

Hyper Location Presence

mHealth Order Refills

Home Security Energy Control

P2P

- Video cameras
- Television
- Digital signage
- Social media
- Contact center

Collaboration as a Service

TelePresence as a Service

Smart Health

5G Enables the Internet of Everything

	2003	2010	2015	2020
World Population (Billion)	6.3	6.8	7.2	7.6
Connected Devices (Billion)	0.5	12.5	25	50
Connected Devices per Person	0.1	1.8	3.5	6.6

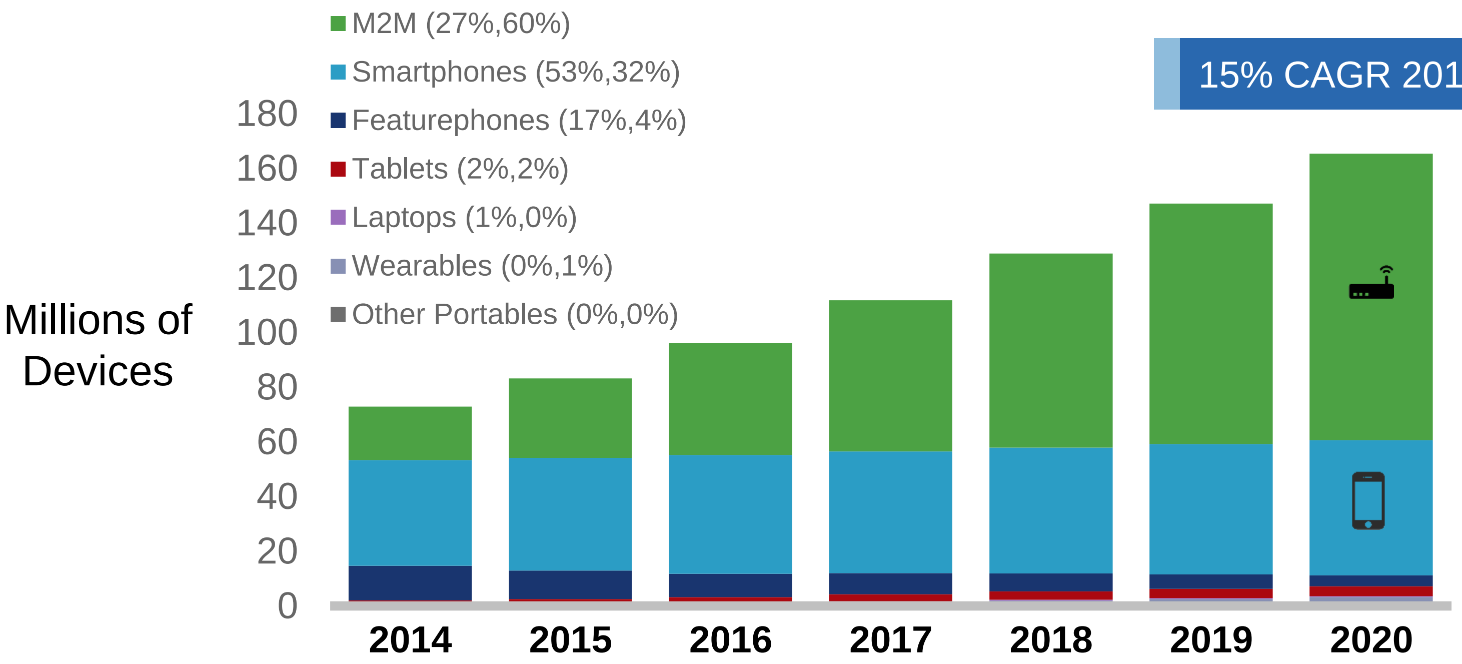
More Devices than People

3G → 4G → 5G

Korea: Mobile Device Growth by Type

Smartphones already dominate share, M2M is growth driver

15% CAGR 2014–2019



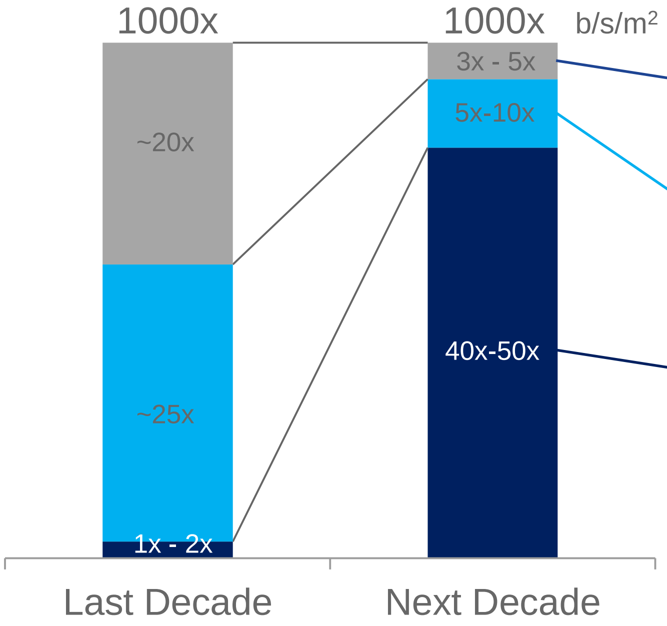
2020:
- 165M Devices
- 230M Connections
- 46M Users

*** Figures (n) refer to 2014, 2019 device share**

Source: Cisco VNI Global Mobile Data Traffic Forecast, 2014–2019

5G: Role of HetNet

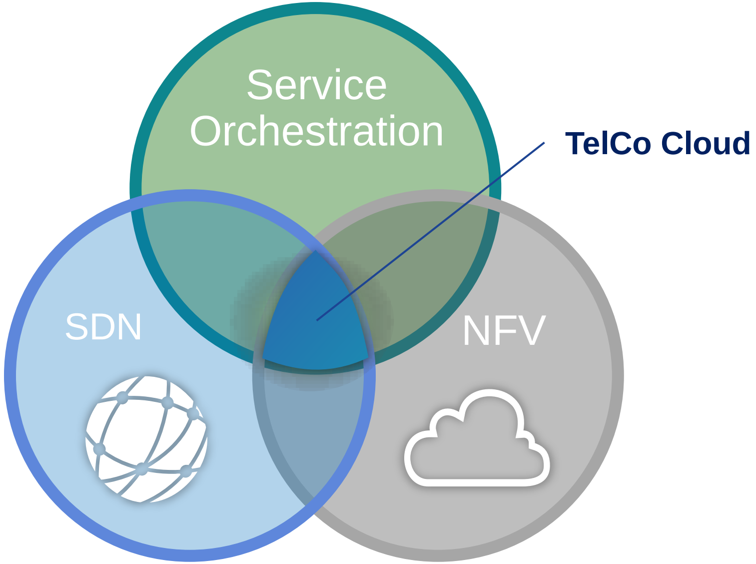
Trends of Network Capacity Growth



Air Interface	• Coordinated Multipoint Tx/Rx • 3-D/Full-Dimensional MIMO • New Modulation and/or Coding Schemes
Spectrum	• More Licensed and Unlicensed Spectrum, Millimetre-Wave Bands • Licensed Shared Access • Unlicensed Spectrum Sharing
Network Devices	• Cell Densification • Wireless Local Area Networks (WLAN) Offloading • Integrated Multiple Radio Access Technology (RAT) Operation • Device-to-Device • Joint Scheduling • Information & Communication Technology Coupling

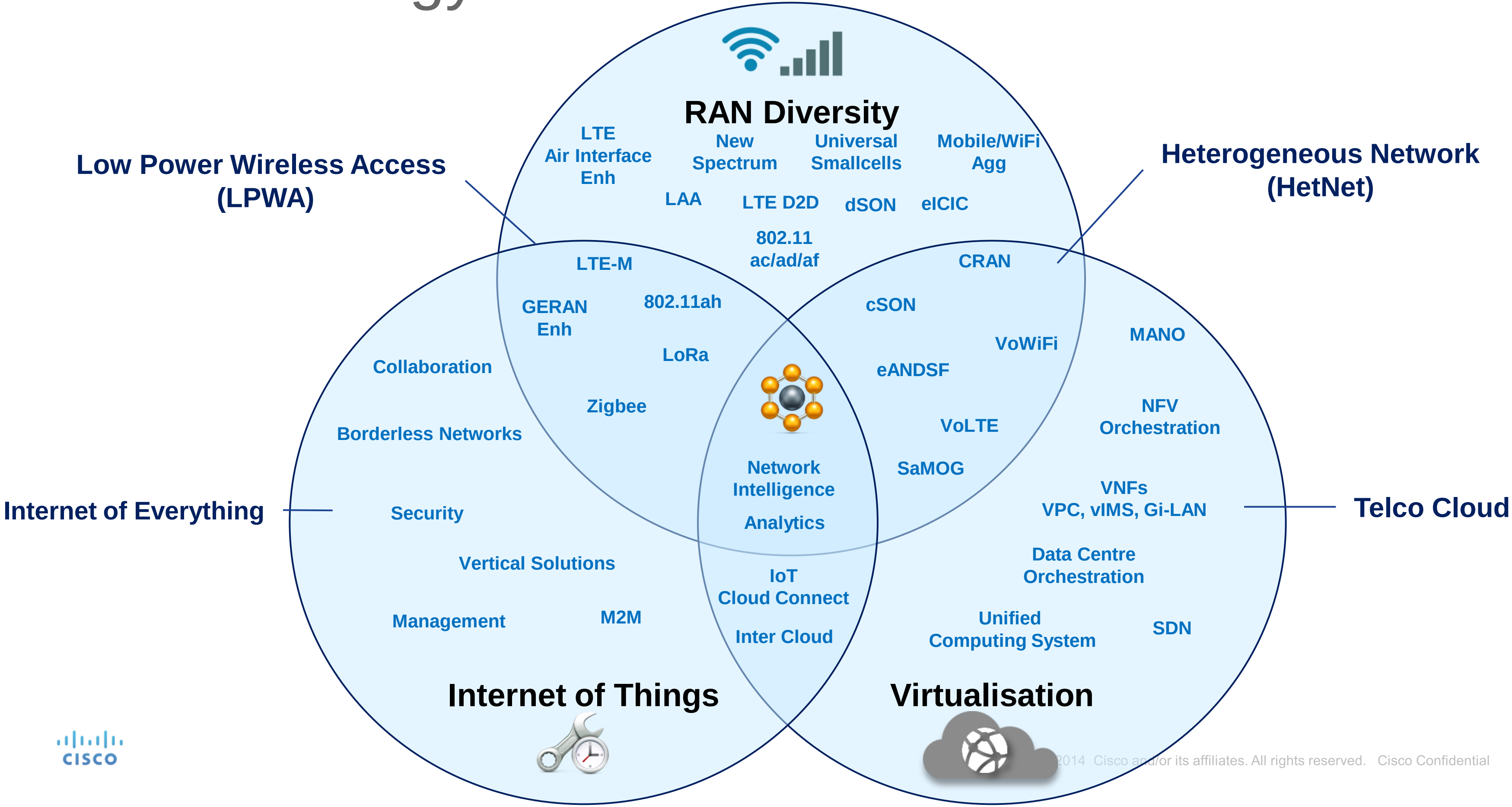
Source: 5G Network Capacity, Key Elements and Technologies, Qian (Clara) Li, Huaning Niu, Apostolos (Tolis) Papathanassiou, and Geng Wu, Jan 2014

5G: The role of SDN and NFV

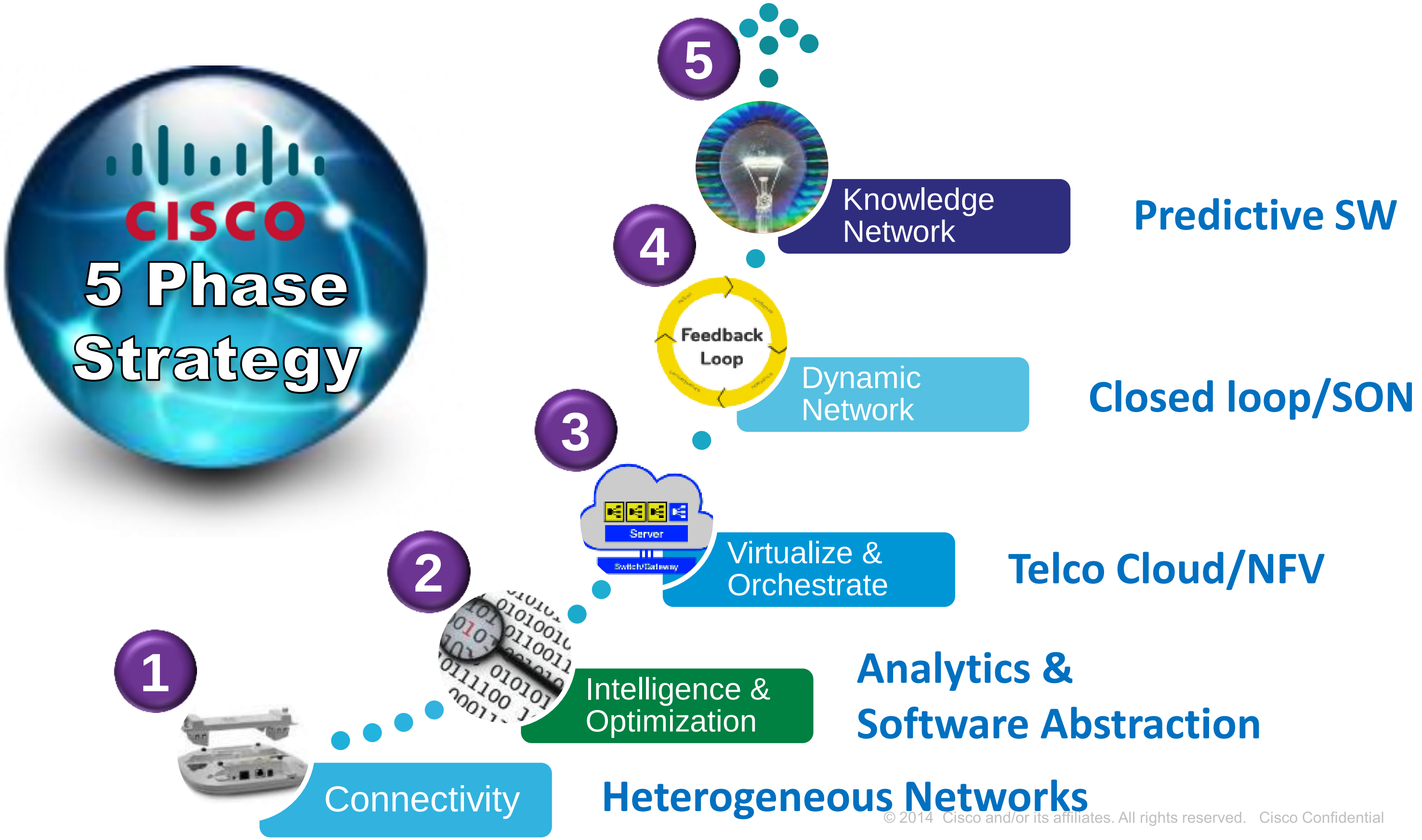


- 5G TCO and flexibility demands **Orchestrated** software-based virtualised network resources.
- Optimised virtual network functions (**NFV**) tailored to each application requirements, e.g.
  - M2M Telemetry
  - M2M Video
  - Mobile Internet
  - Enterprise Cloud Services
  - Public Safety, etc.
- Each configured dynamically (**SDN**) using transport & compute resources from the same or different sources based on cost & availability.
  - Centralised and/or distributed
  - Private and/or Public Cloud

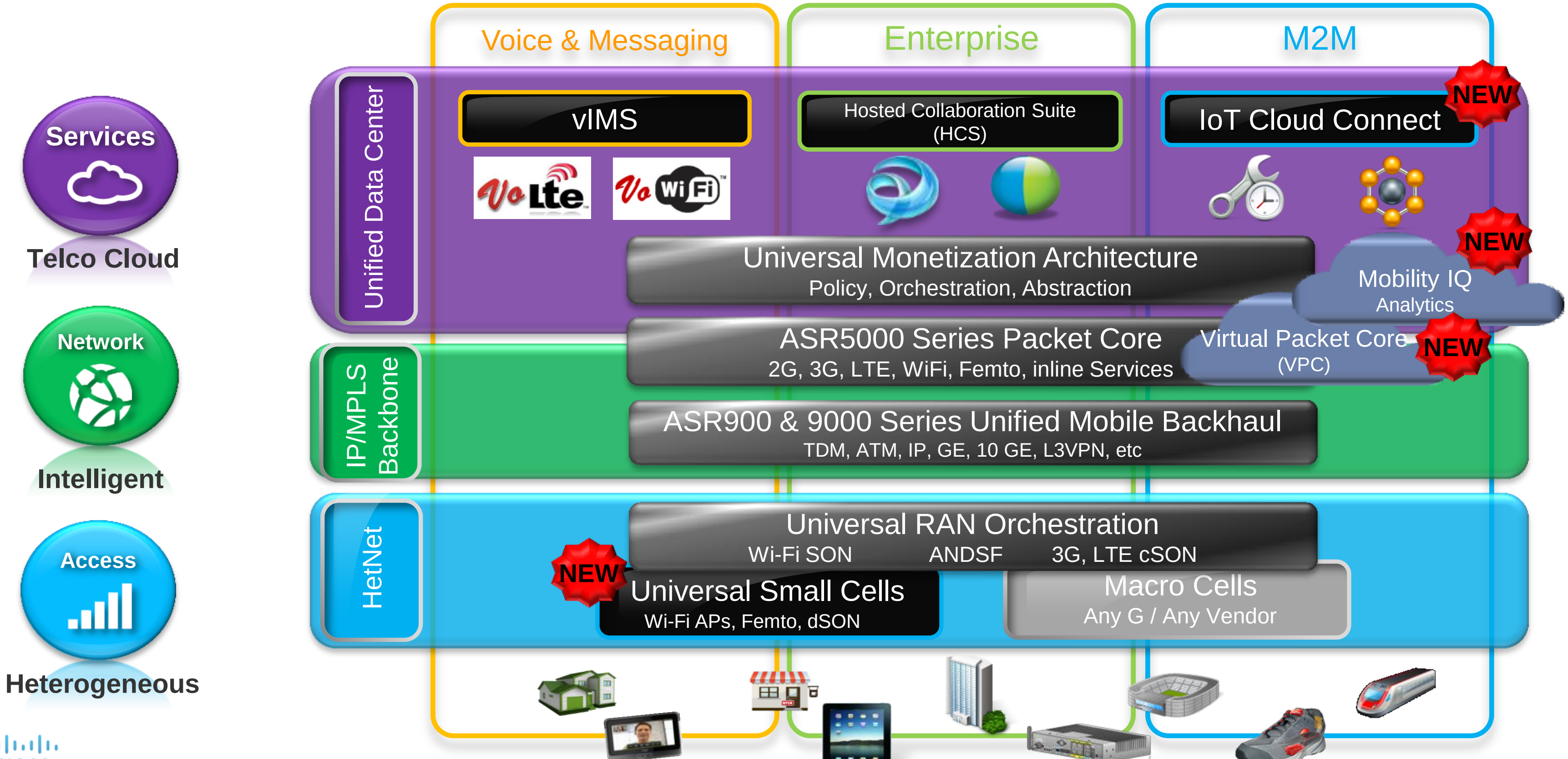
5G: Technology Enablers from Various Sources



Mobile Network Evolution 5 Phase Strategy



Cisco Mobile Internet Architecture



Summary

- 5G is about Evolution not Revolution to a 2020 world
- Mobile first, Video by default, Internet of Everything, Web Apps & Services
- 5G networks will be built on 3 themes:
    1. Internet of Everything Enablers
    2. RAN Diversity
    3. Virtualistion
- Cisco Mobile strategy builds on these to transform 4G networks of today

CISCO *TOMORROW starts here.*

QUALCOMM®

Paving the path to Narrowband 5G with LTE Internet of Things (IoT)

Qualcomm Technologies, Inc.

June, 2016

IoT – a massive surge of smart, interconnected "things"

QUALCOMM®

Qualcomm Technologies, Inc. is a proven, trusted solution provider for IoT

Decades of industry experience

Broad portfolio of technologies

1B+ IoT devices shipped globally[1]

[1] Cumulative shipment using Qualcomm technologies; includes SoC, Cellular, Bluetooth, Wi-Fi , GNSS and PLC, stats as of April 2016

Connecting the IoT requires heterogeneous connectivity

Powered by global standards with seamless interoperability across multiple vendors

Cellular

Wi-Fi

Bluetooth

GNSS/Location

NFC

Powerline

Creating a connectivity fabric for everything

To support the wide range of IoT use cases with varying requirements

Throughput

Reliability

Node density

Coverage

Security

Cost

Battery life

Latency

Mobility

Cellular technologies enable a wide range of IoT services

>5B
IoT connections by 2025[1]

Smart cities
Lighting, traffic sensors, smart parking,…

Mobile health
Wearables, gateways, remote patient,…

Smart utilities
Smart grid, gas/water/ electric meters

Environmental monitoring
Agriculture, forecast fire/ air pollution sensors,…

Connected building
Security, video surveillance, smoke detectors,…

Connected industrial
Process/equipment monitoring, HVAC, …

Connected retail
Vending machines, ATM, digital ads,…

Asset tracking
Fleet management, pet/kid trackers, shipping,…

Ubiquitous coverage	Always-on connectivity	Reliable and secure	Global ecosystem

[1] Including Cellular & LPWA M2M connections, Machina Research, June, 2016

We are evolving LTE for the Internet of Things

New narrowband technologies to more efficiently support IoT use cases

← Scaling up in performance and mobility

Scaling down in complexity and power →

Today

New narrowband IoT technologies (3GPP Release 13+)

LTE Cat-4 and above	LTE Cat-1	LTE Cat-M1 (eMTC)	Cat-NB1 (NB-IoT)
>10 Mbps	Up to 10 Mbps	Variable rate up to 1 Mbps	10s of kbps
n x 20 MHz	20 MHz	1.4 MHz narrowband	200 kHz narrowband

Mobile

Video security

Wearables

Object tracking

Utility metering

Environment monitoring

Connected car

Energy management

Connected healthcare

City infrastructure

Smart buildings

LTE IoT delivers significant value for LPWA[1] applications

Over non-3GPP solutions

Ubiquitous coverage
Established networks serving billions of connections worldwide

Scalability
To address the wide range of IoT use cases

Coexistence
Leverages existing and planned LTE infrastructure and spectrum

Mature ecosystem
Backed by global standards with a rich roadmap to 5G

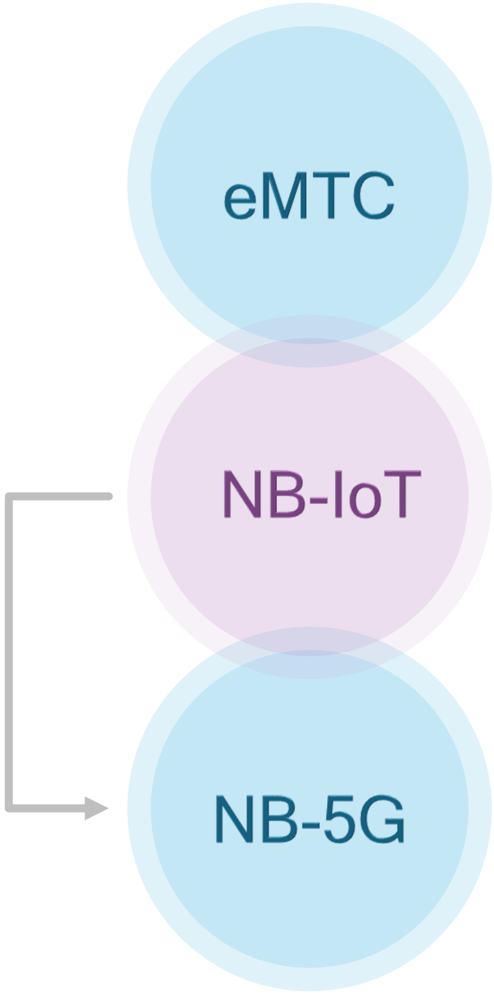
Managed QoS
Based on licensed spectrum with a redundant network design

End-to-end security
Established/trusted security and authentication features built in

[1] Low-power, wide-area

Paving the path to 5G

NB-IoT is the foundation for Narrowband 5G; continuing to evolve in Release 14+



Scales down LTE to address the broadest range of IoT use cases

Optimizes to lowest cost/power for delay-tolerant, low-throughput IoT use cases

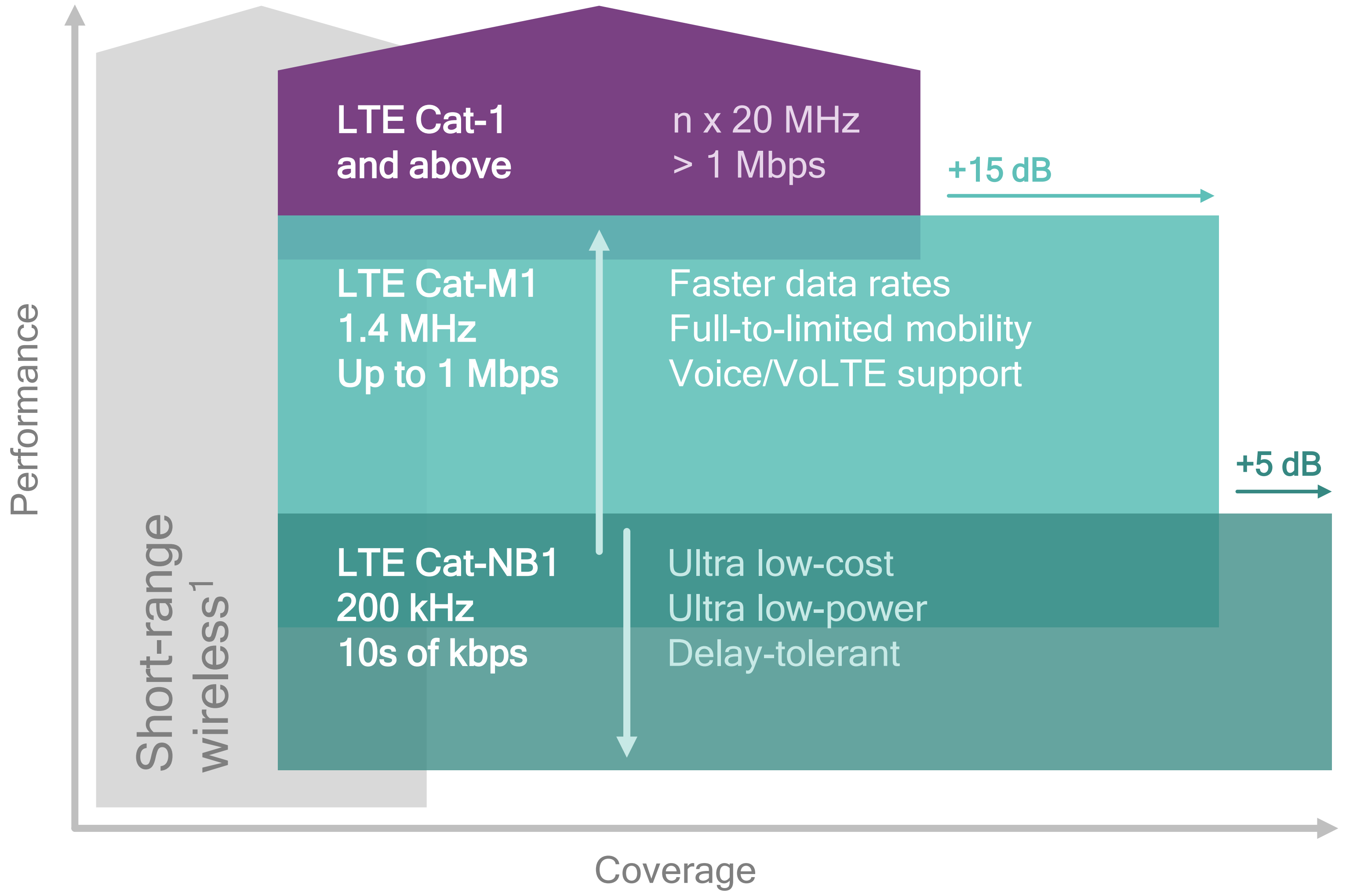
3GPP 5G NR further enhances massive IoT with new capabilities such as RSMA[1] & multi-hop mesh

[1] Resource Spread Multiple Access

Delivering new narrowband LTE IoT technologies

As part of 3GPP Release 13

Two new LTE IoT technologies, one unified LTE platform



LTE Cat-M1 (eMTC)

Broadest range of IoT capabilities with support for advanced features, e.g. voice support

Many IoT devices can benefit from multi-mode operations to optimize for different traffic profiles and RF conditions

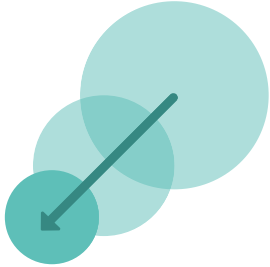
LTE Cat-NB1 (NB-IoT)

Scalable to lowest cost/power for delay-tolerant, low-throughput IoT use cases, e.g. remote sensors

[1] Examples include Bluetooth, Wi-Fi, NFC, and others

LTE IoT reduces complexity, extends battery life & coverage

Through optimizations to both the air interface and core network

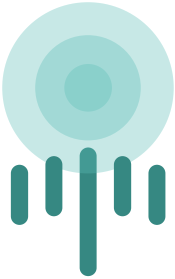


Reduced complexity

Narrowband operation (1.4 MHz or 200 kHz) plus further device and core network complexity reductions

Multi-year battery life

Enhanced power save modes and more efficient signaling, e.g. extended DRX sleep cycles



Deeper coverage

Achieve up to 20 dB increase in link budget for hard-to-reach locations via redundant transmissions

Higher node density

Signaling and other network optimizations, e.g. overload control, to support a large number of devices per cell

Coexistence with today’s mobile broadband services

Leveraging existing infrastructure and spectrum

New LTE IoT device categories reduce LTE complexity

To enable low-cost modules optimized for small, infrequent data transmissions

	LTE Cat-1 (Today)	LTE Cat-M1 (Rel-13)	LTE Cat-NB1 (Rel-13)
Peak data rate	DL: 10 Mbps UL: 5 Mbps	DL: 1 Mbps UL: 1 Mbps	DL: ~20 kbps UL: ~60 kbps
Bandwidth	20 MHz	1.4 MHz	200 kHz
Rx antenna	MIMO	Single Rx	Single Rx
Duplex mode	Full duplex FDD/TDD	Supports half duplex FDD/TDD	Half duplex FDD only
Transmit power	23 dBm	20 dBm[1]	20 dBm[1]

← Higher throughput, lower latency, full mobility

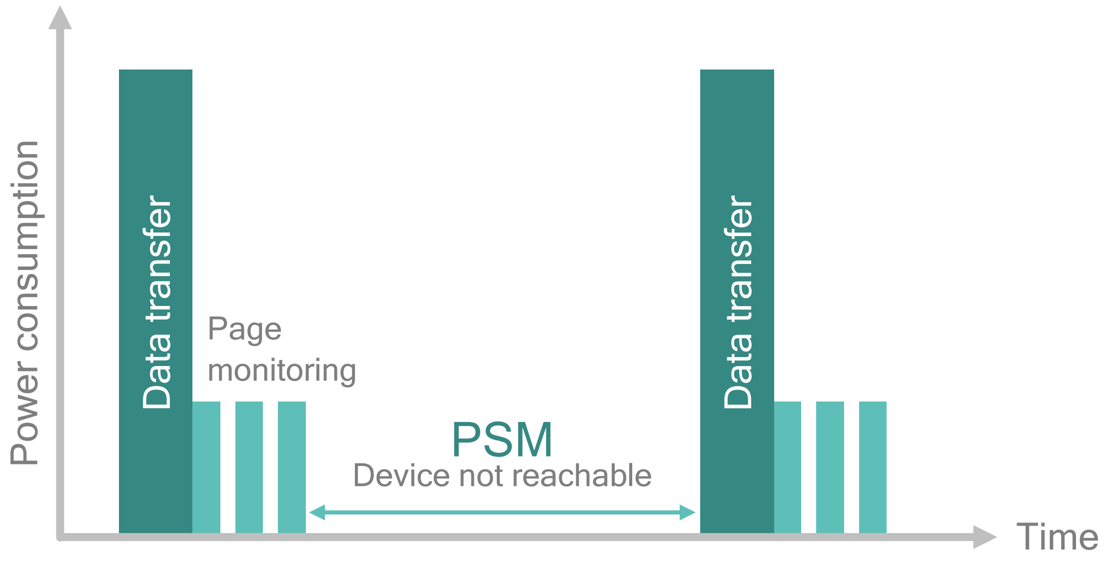
Simplified RF hardware

Reduces baseband complexity and decreases memory

[1] Integrated PA possible

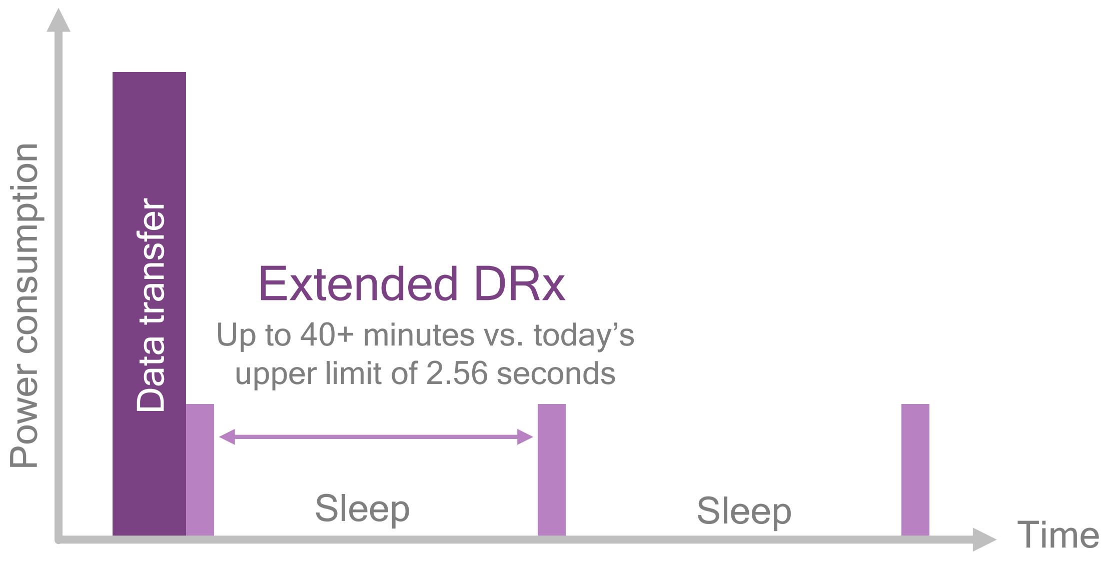
Delivering multi-year battery life

Devices wake up on a per-need basis; stay asleep for minutes, hours, even days



Power save mode (PSM)

Eliminates page monitoring between data transmissions
For device-originated or scheduled applications, e.g., smart metering, environmental monitoring



Extended discontinuous receive (eDRx)

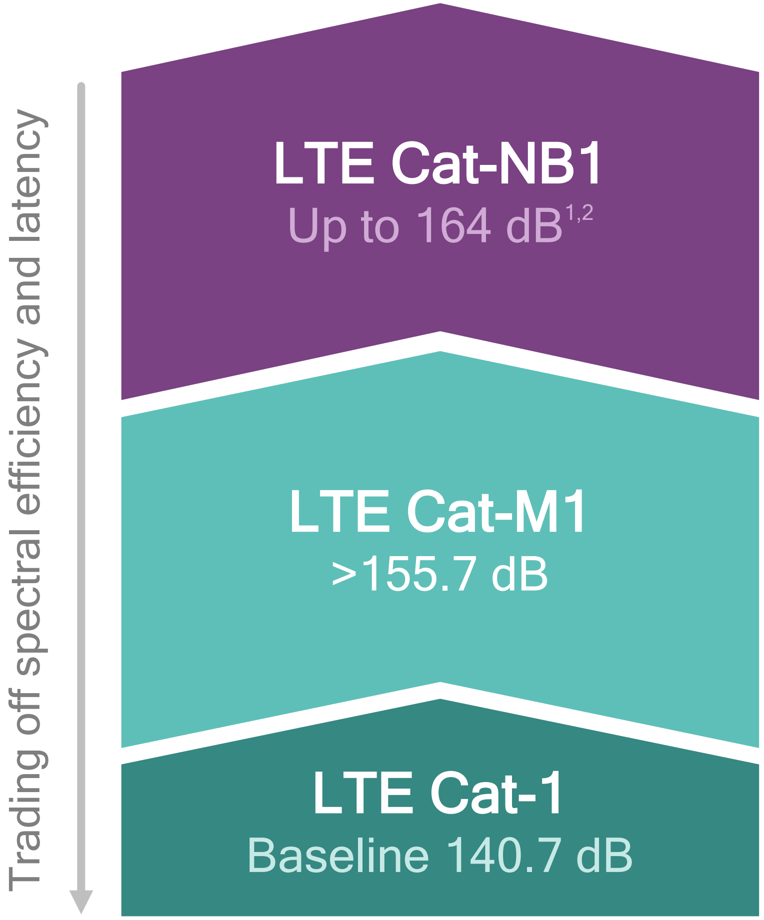
Extends time between monitoring for network messages
For device-terminated applications, e.g., object tracking, smart grid

Also features such as reduced complexity and less channel measurements extend battery life

Note: PSM and eDRx applicable to both Cat-M1 and Cat-NB1; may also be applied to LTE Cat-1 and above

Numerous technology enablers for deeper coverage

To reach challenging locations, e.g. penetrating more walls & floors



Cat-NB1 only

- Further relaxed requirements, e.g. timing
- Low-order modulation, e.g. QPSK
- Option for single-tone uplink transmissions

Cat-M1 and Cat-NB1

- Repetitive transmissions & TTI bundling for redundancy
- Narrowband uplink transmissions

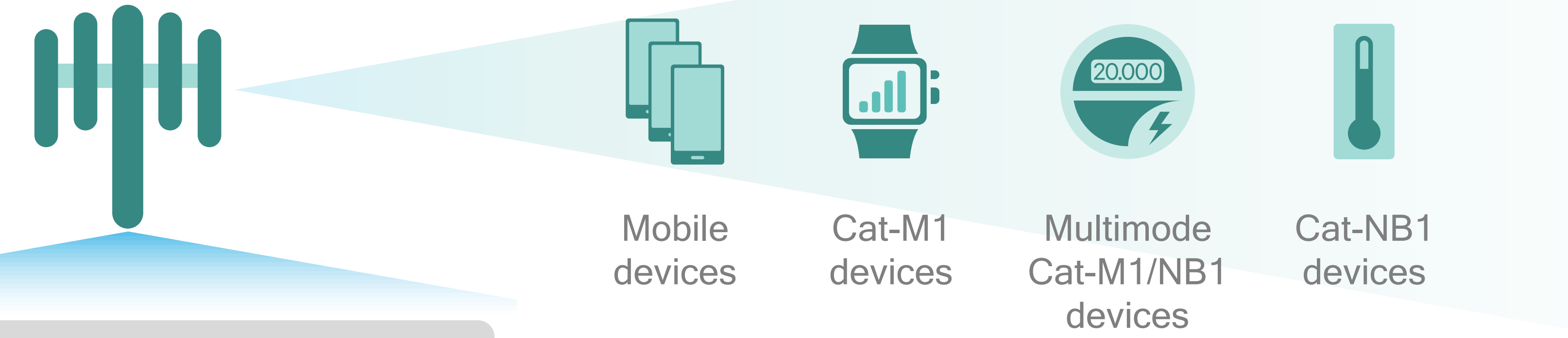
[1] Link budget; [2] At least for standalone operation mode

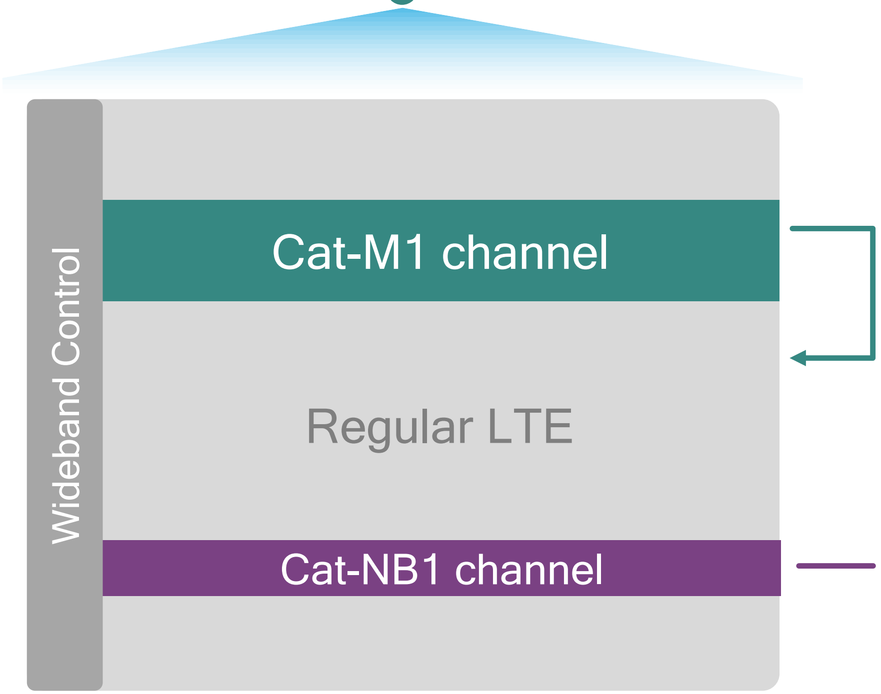
Coexisting with today’s LTE services

Cat-M1 and Cat-NB1 can leverage existing LTE infrastructure and spectrum

<0.1%

Data capacity for IoT traffic based on sample scenario[1]





Reuse center 6 PRB[2] for synchronization; data channel can operate across entire LTE band for most efficient coexistence with today’s traffic

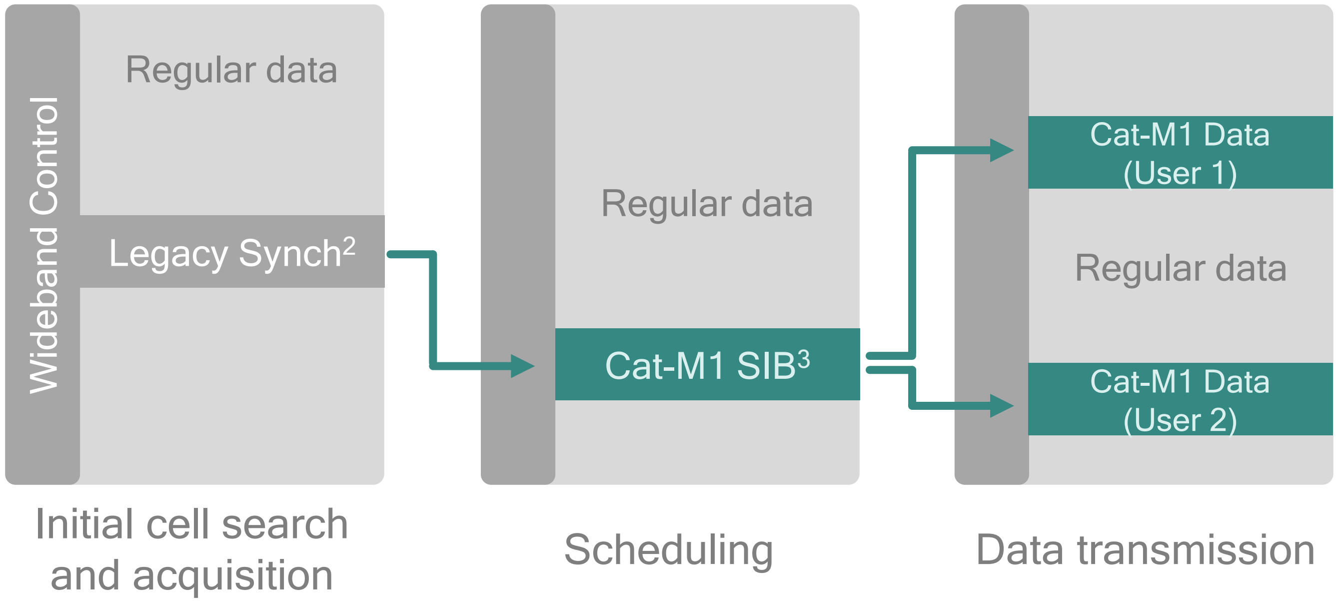
New synchronization anchor channels are in restricted narrowband locations; may also be deployed standalone[3] or in LTE guard band

[1] Assumptions: ISD Urban - 500m, 3 cells per site, Channel b/w 10MHz, Cell capacity: DL 14Mbps, UL 9.6Mbps; Traffic types include data and commands for Electric Meter, Water Meter, Security Panel, HVAC - Residential, Outdoor Street Light, Off Street Parking Meter, Parking Space Sensor, Water Assets; 100% of traffic assumed in 6hr. busy period; [2] Physical Resource Block; [3] Including re-farming of GSM spectrum

Cat-M1 (eMTC) efficient coexistence with today's services

Narrowband operation of 1.4 MHz[1] across entire LTE band

Supports FDD or TDD spectrum



Co-existence

Time and Frequency-Division Multiplexing between LTE IoT and today's existing services, e.g. mobile broadband

Flexible capacity

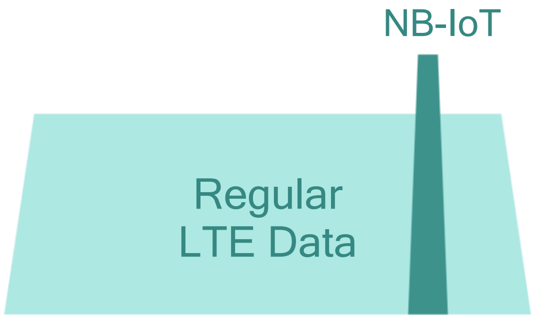
Multiple narrowband regions with frequency retuning to support scalable resource allocation between LTE IoT and non-IoT traffic[4]

[1] 1.08 MHz used by the network to transmit 6 RBs in-band; [2] PSS/SSS/PBCH; [3] SIB (System Information Block); [4] Also supports frequency hopping within LTE band for diversity

Cat-NB1 (NB-IoT) flexible deployment options

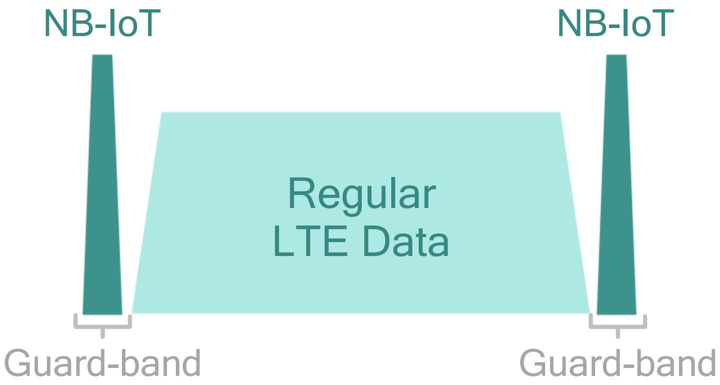
Dedicated NB carrier – supports FDD spectrum only in Rel-13

In-band



Utilizing single Resource Block (180 kHz) within a normal LTE carrier

Guard-band



Utilizing unused resource blocks within a LTE carrier's guard-band

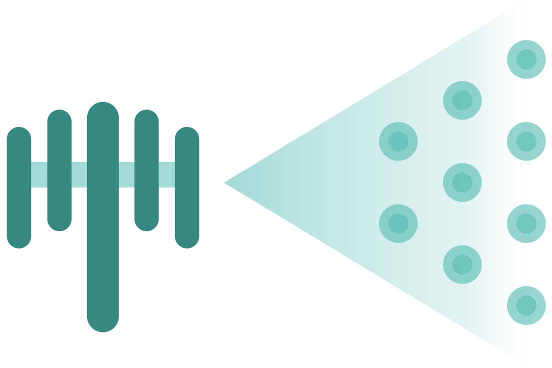
Standalone

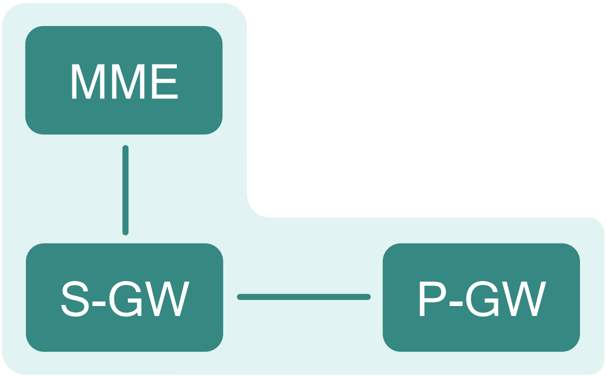
Utilizing stand-alone 200 kHz carrier, e.g. re-farming spectrum currently used by GERAN systems

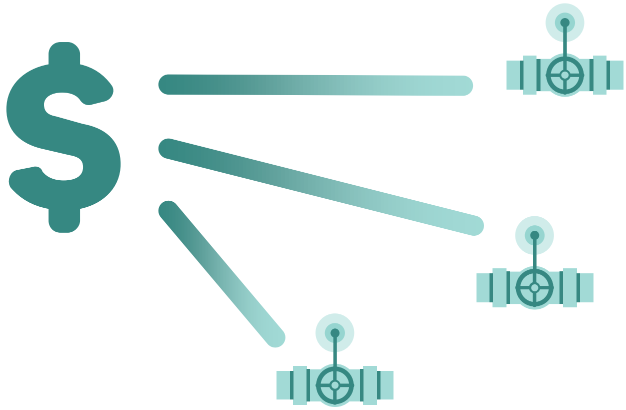
New optimized NB-IoT synchronization, control, and data channels

Delivering IoT optimizations to the network architecture

Also part of 3GPP Release 13







More efficient signaling

To support a larger number of devices per cell with new features such as group-based paging and messaging

Simplified Core Network (EPC-lite)

Reduced functionality, e.g. limited mobility and no voice, makes possible for integrating network functions into a single entity

Enhanced resource management

Such as optimizations to allow a large set of devices to share the same subscription, e.g. all the water meters in a city

Optional optimizations so that mobile operators can effectively balance CAPEX vs. OPEX decisions

Small cells add value to LTE IoT deployments

Venues | Industrial | Residential | Enterprise/Buildings | Cities

Improved coverage

Bringing the network closer for deeper reach indoors and more reliable connectivity

Longer battery life

Allowing devices to reduce uplink transmit power, minimizing overall power consumption

More deployment options

Leveraging neutral hosts to provide IoT connectivity in shared/unlicensed spectrum (e.g. MulteFire)

Providing an end-to-end LTE IoT platform

To simplify the deployment and management of IoT services

Simplified device development

Development platforms
Certified modules
Certified devices

Optimized LTE connectivity

Reduced complexity
Lower power
Deeper coverage

Simplified service management

Billing/cost mgmt.
Remote provisioning
Embedded SIM (eUICC)
Real-time diagnostics

Simplified network architecture

Reduced functionality
Optimized signaling
Virtualization

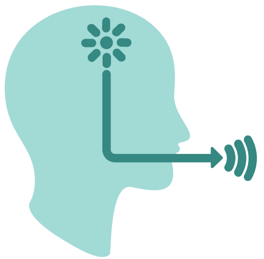
Simplified application development

Standardized protocols
Interoperability
End-to-end security
e.g. oneM2M

Roadmap to 5G will bring even more opportunities for the Internet of Things

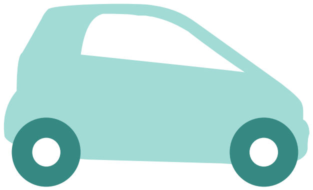
We are continuing to evolve NB-IoT beyond Release 13

The foundation to Narrowband 5G



VoLTE

Adding voice and options to support lower latency services



Mobility

Enabling devices to monitor and report channel conditions for inter-cell handovers

Positioning

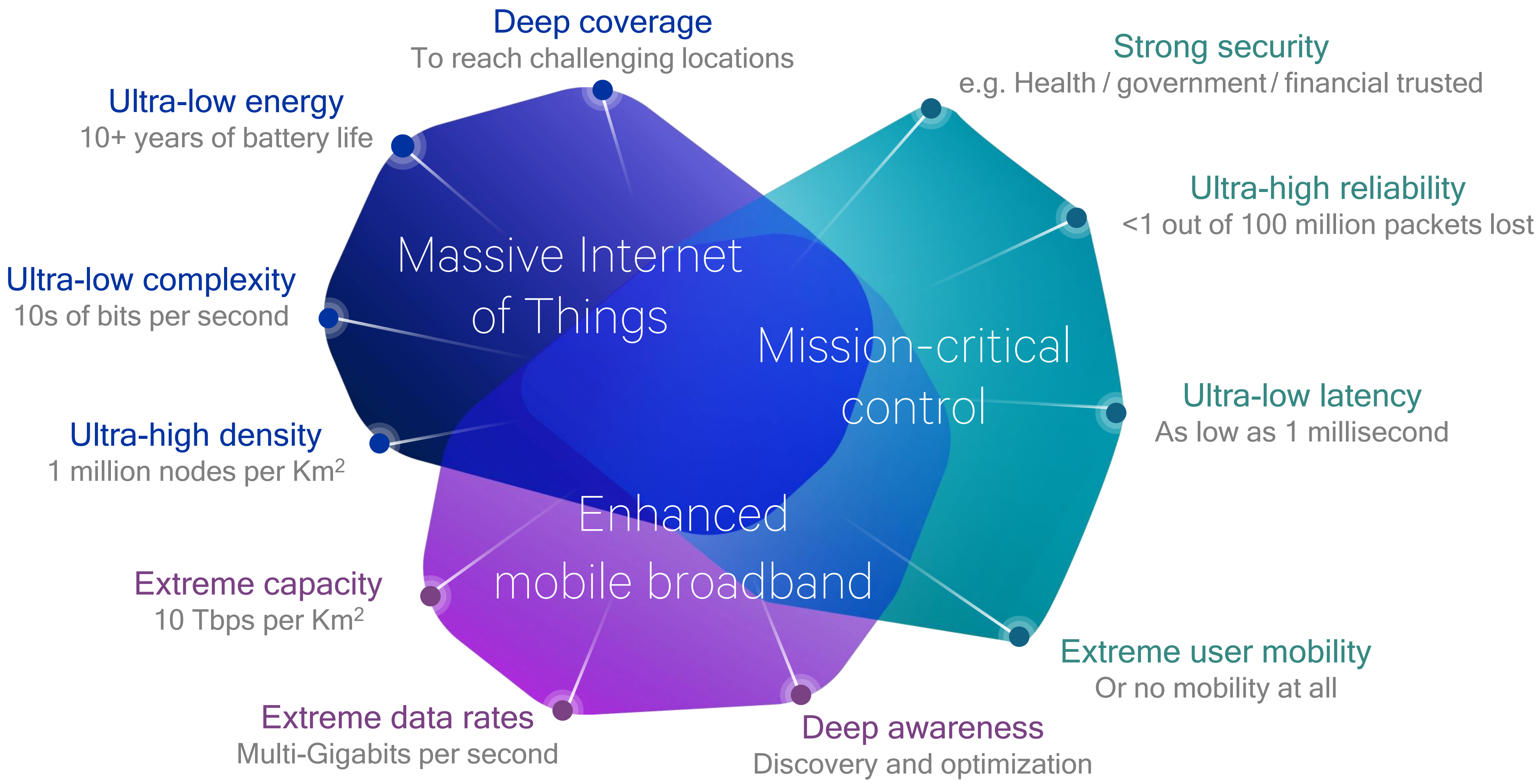
Providing location services for use cases such as mobile asset tracking and emergency call

Broadcast

Allowing more efficient OTA firmware update for large number of devices, e.g. sensors, meters

We are also designing a new 5G NR air interface

5G NR will be scalable to an extreme variation of IoT requirements

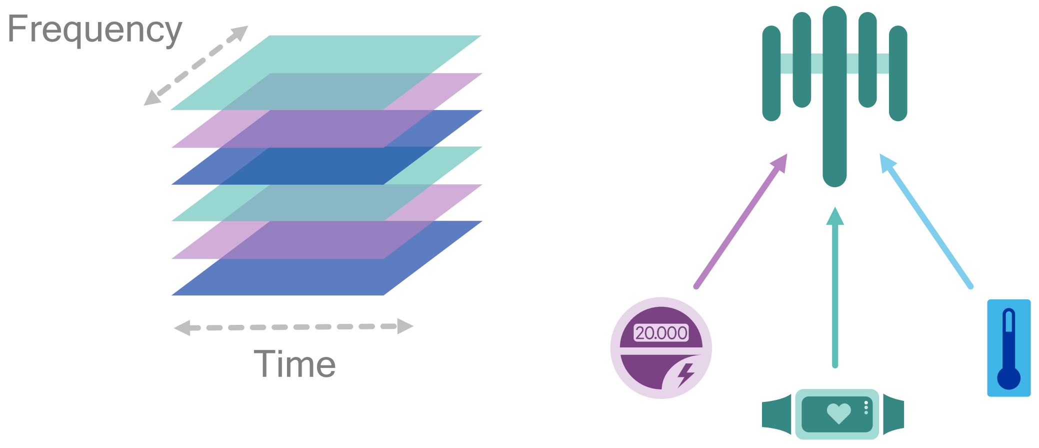


Based on target requirements for the envisioned 5G use cases

Bringing new capabilities for the massive IoT

Grant-free uplink

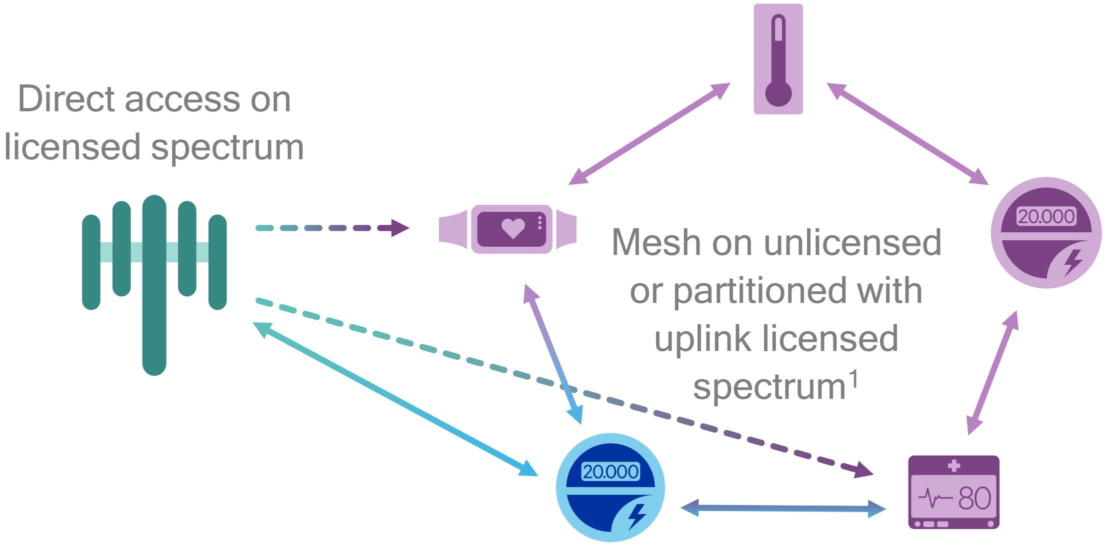
Resource Spread Multiple Access (RSMA)



Enables asynchronous, non-orthogonal, contention-based access that is well suited for sporadic uplink transmissions of small data bursts common in IoT use cases

Coverage extension

Multi-hop mesh with WAN management

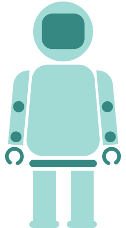


Overcomes uplink coverage issues due to low-power devices and challenging placements by enabling uplink data relayed via nearby devices; opportunity to reduce power/cost even further

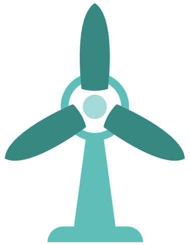
[1] Greater range and efficiency when using licensed spectrum, e.g. protected reference signals . Network time synchronization improves peer-to-peer efficiency

Also enabling new mission-critical control IoT services

Autonomous vehicles



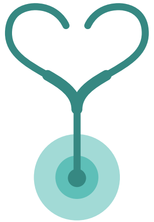
Robotics



Energy/ Smart grid

Aviation

Industrial automation



Medical

1ms e2e latency

Faster, more flexible frame structure; also new non-orthogonal uplink access

Ultra-high reliability

Ultra-reliable transmissions that can be time multiplexed with nominal traffic through puncturing

Ultra-high availability

Simultaneous links to both 5G and LTE for failure tolerance and extreme mobility

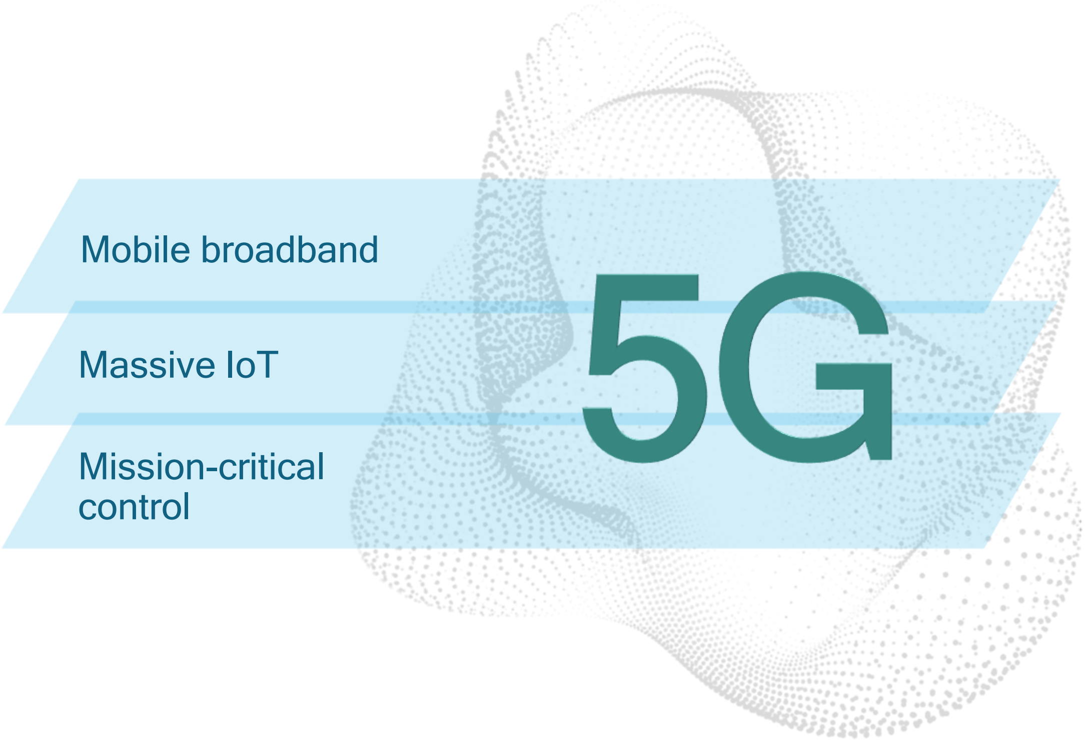
Strong e2e security

Security enhancements to air interface, core network, & service layer across verticals[1]

[1] Also exploring alternative roots of trust beyond the SIM card

Flexible 5G network architecture brings additional benefits

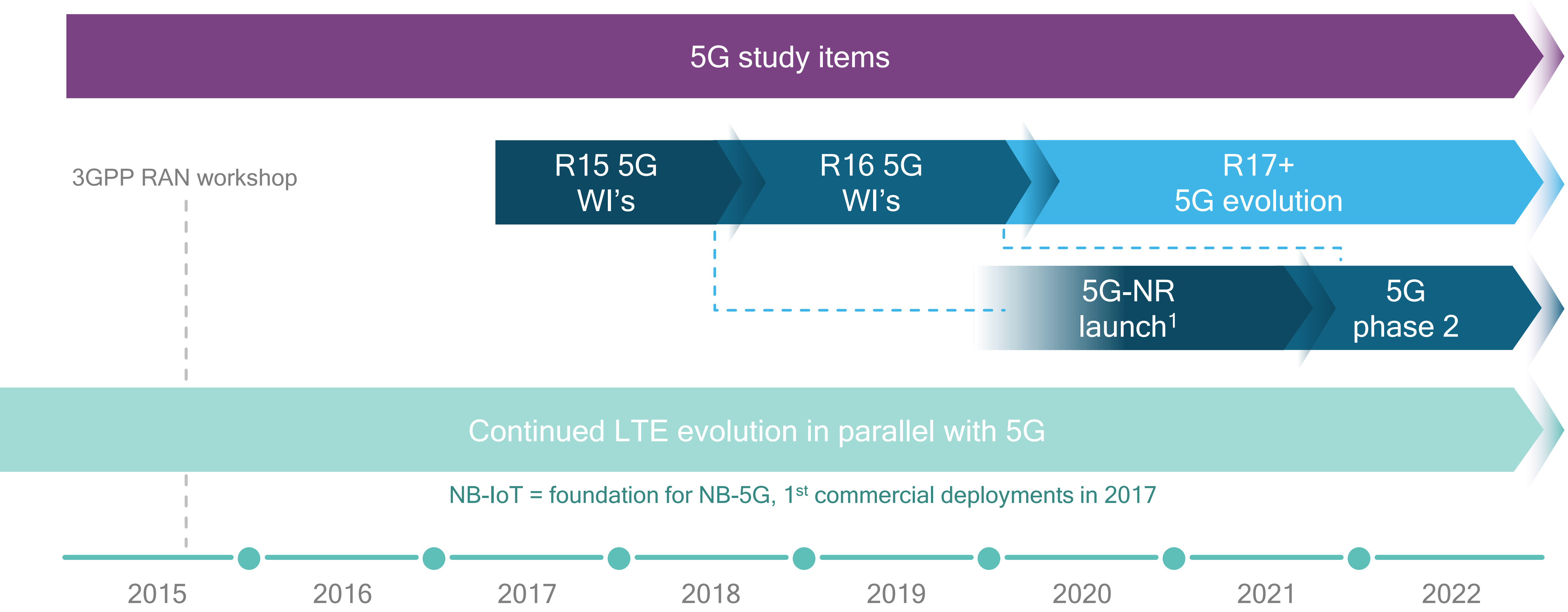
Leveraging virtualized network functions to create optimized network slices



- Configurable end-to-end connectivity per vertical
- Modular, specialized network functions per services
- Flexible subscription models
- Dynamic control and user planes with more functionality at the edge
- Multi-access core network will provide connectivity to LTE, NB-IOT, and 5G IoT

Better cost/ Energy efficiency	Optimized performance	Flexible business models	Dynamic creation of services

5G standardization progressing for 2020 launch



Learn more at: www.qualcomm.com/5G

Note: Estimated commercial dates; [1] Forward compatibility with R16 and beyond

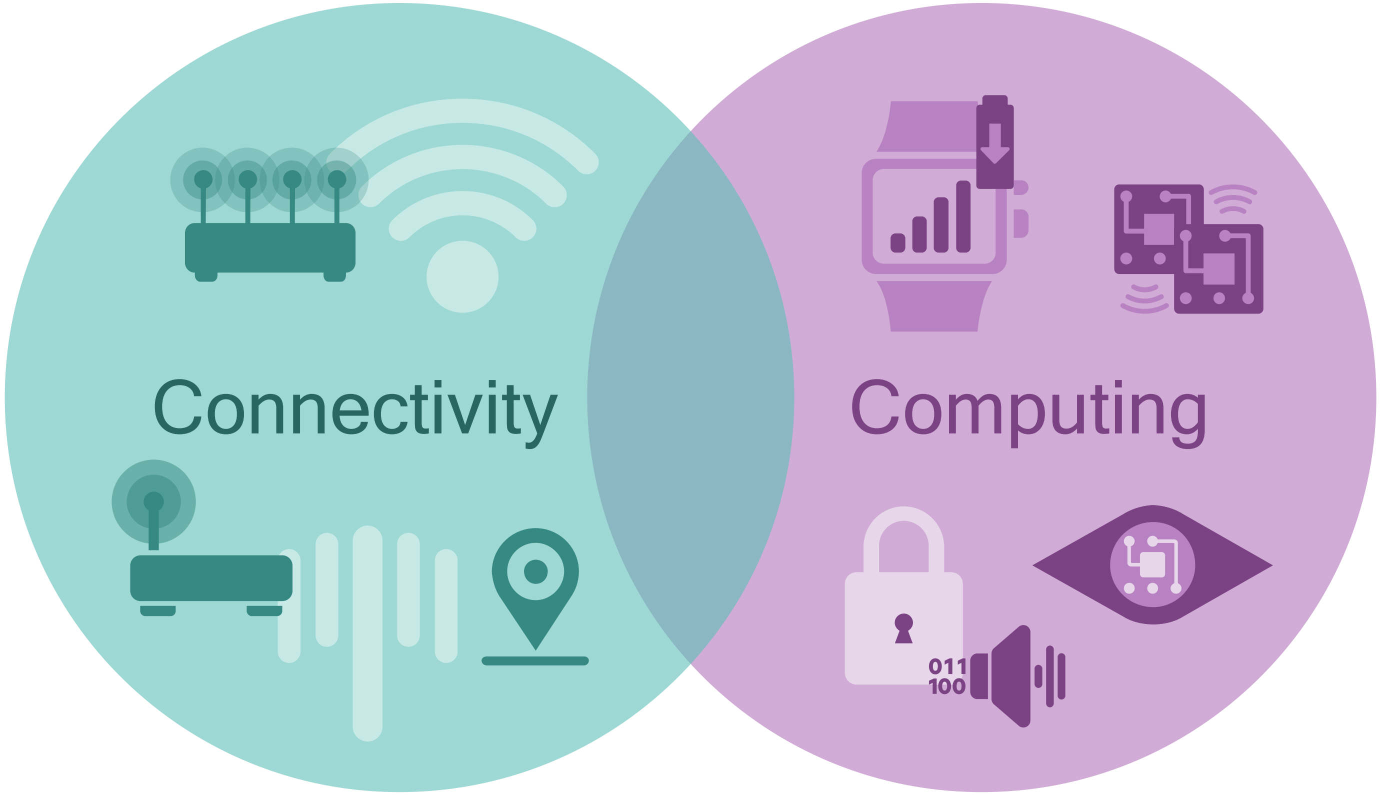
Qualcomm is uniquely positioned to connect the Internet of Things

An established leader today –
pioneering tomorrow's technologies

Delivering a broad portfolio of technologies for the IoT

To meet diverse connectivity and computing requirements

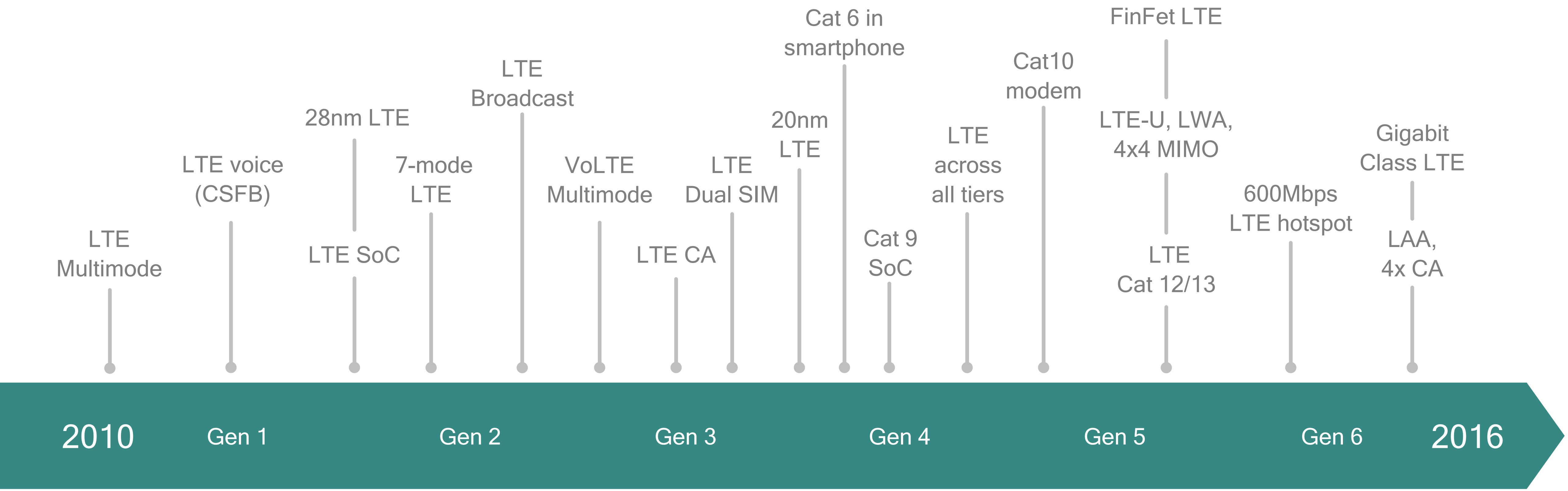
- Bluetooth Smart
- Bluetooth Mesh
- 802.11ac
- 802.11ad
- 802.11n
- DSRC
- NFC
- 3G
- 4G LTE
- 5G
- Powerline
- GNSS/Location



- Cognitive computing
- Camera processing
- Audio processing
- Sensor core
- Security
- CPU
- GPU
- DSP
- Media processing
- Augmented reality
- Display processing
- Power management

Qualcomm Technologies' LTE platform leadership

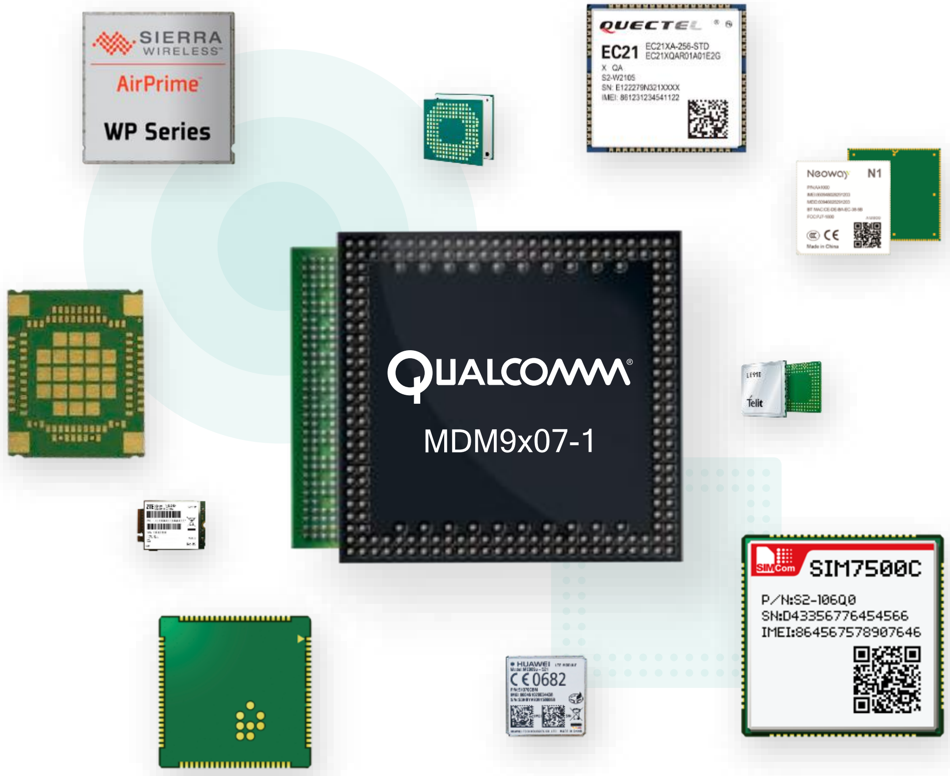
A history of industry firsts



Qualcomm Technologies modem generation and feature

Delivering 3G and 4G LTE solutions for the IoT today

Established ecosystem partners with proven global solutions



Qualcomm MDM9x07-1: LTE Cat-1 modem for the Internet of Things

- 4G/3G global band support (multimode/multiband)
- Highly integrated to reduce cost / complexity
- PSM enabling up to 10+ years battery life
- Scalable to add voice, Wi-Fi, BT capabilities
- Hardware-based security

More than 100 design wins from over 60 manufacturers[1]

[1] Includes Qualcomm Snapdragon X5 LTE (9x07) and MDM9x07-1 modem, as of June 2016

Qualcomm Snapdragon, MDM9x07 and MDM9x07-1 are products of Qualcomm Technologies, Inc.

Driving new LTE IoT technologies towards commercialization

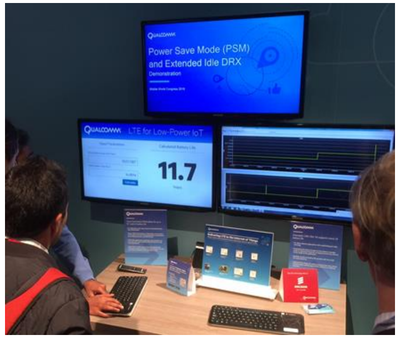
Rel-13 specification now complete for LTE Cat-M1 (eMTC) and Cat-NB1 (NB-IoT)

Standards leadership

Main contributor to eMTC and NB-IoT features

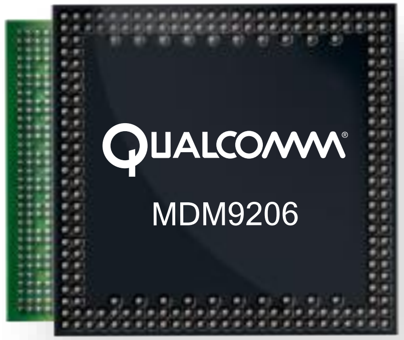
Harmonized Industry on narrowband IoT (NB-IoT) specification

Pioneering work on future IoT technologies, e.g. multi-hop to extend uplink coverage



Prototyping new technologies

PSM & eDRx simulations and system tests, as demonstrated at MWC 2016



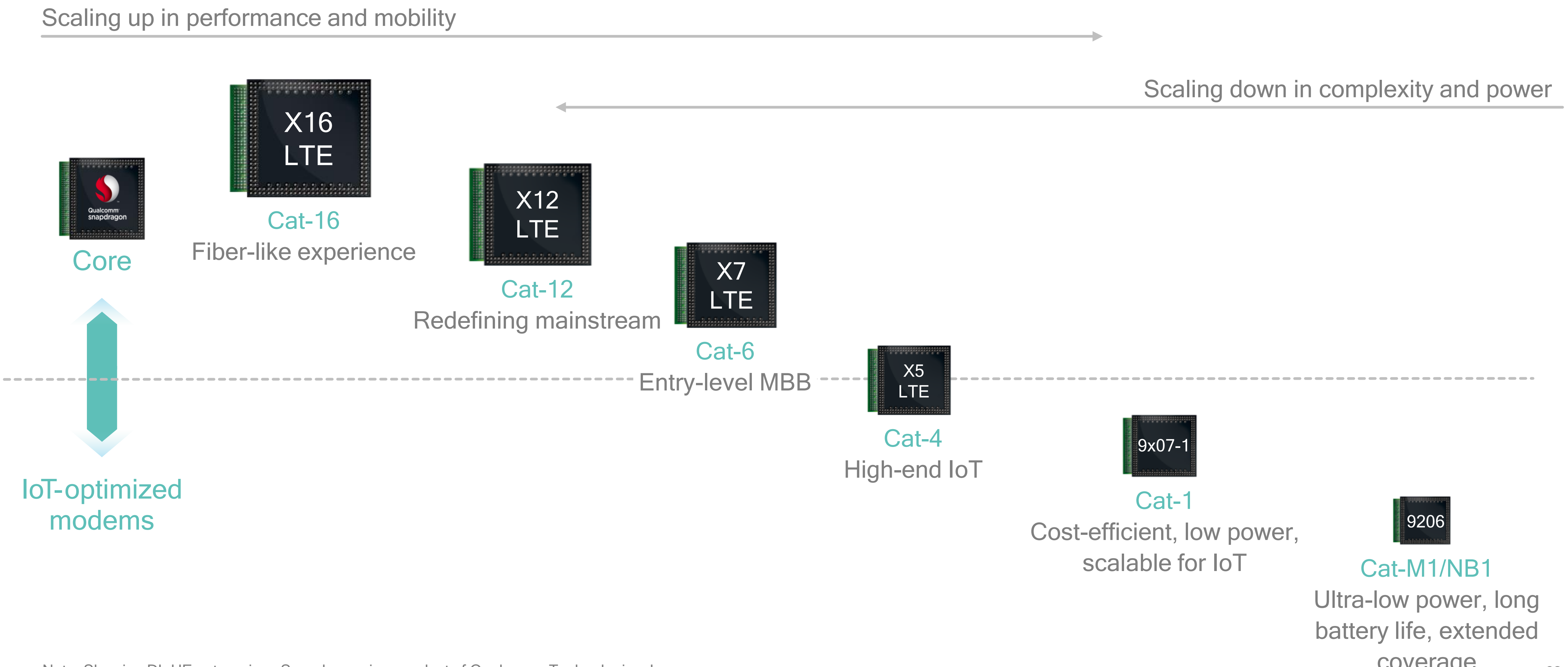
Qualcomm MDM9206 Flexible chipset platform

Common hardware solution to enable Cat-M1 and/or Cat-NB1

MDM9206 is a product of Qualcomm Technologies, Inc.

Delivering a scalable roadmap across all tiers & segments

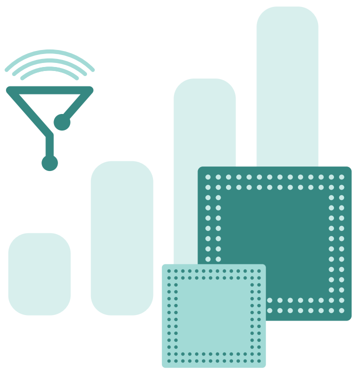
LTE from gigabit to micro-amp



Note: Showing DL UE categories. Snapdragon is a product of Qualcomm Technologies, Inc.

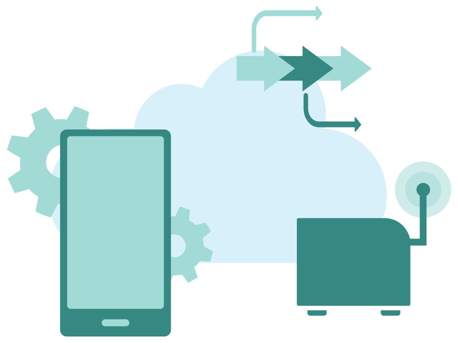
Leading the world to 5G

Investing in 5G for many years—building upon our leadership foundation



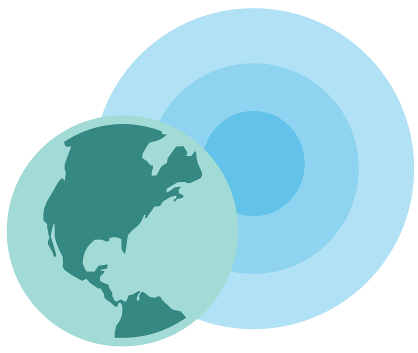
Wireless/OFDM technology and chipset leadership

Pioneering new 5G technologies to meet extreme requirements



End-to-end system approach with advanced prototypes

Driving 5G from standardization to commercialization



Leading global network experience and scale

Providing the experience and scale that 5G demands

In summary

LTE is evolving to deliver a unified, scalable IoT platform that brings significant benefits over non-3GPP LPWA solutions

Delivering new narrowband IoT technologies (Cat-M1/NB1) to lower complexity, increase battery life, and deepen coverage – establishes the foundation for Narrowband 5G

Roadmap to 5G will bring even more opportunities for the Internet of Things including new mission-critical services

Qualcomm is uniquely positioned to connect the Internet of Things and is leading the world to 5G

Learn more at: http://www.qualcomm.com/LTE-IoT

Questions? - Connect with Us

www.qualcomm.com/wireless

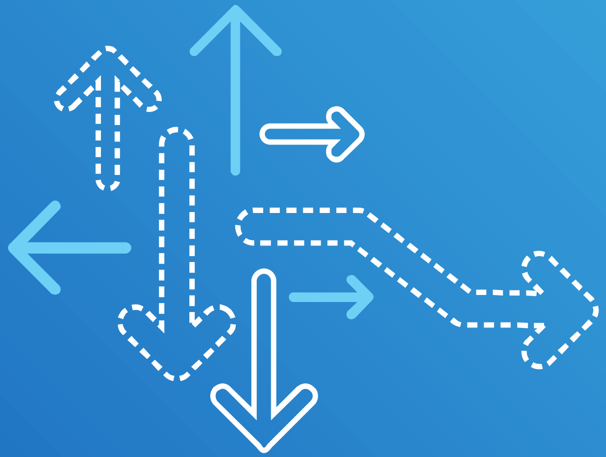
BLOG

www.qualcomm.com/news/onq

@Qualcomm_tech

http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp

http://www.slideshare.net/qualcommwirelessevolution



Thank you

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Information-Centric IoT over 5G

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(Huawei Research Lab, Santa Clara)
(Fall 2015 Research Review, Winlab/Rutgers, Dec 4th, 2015)

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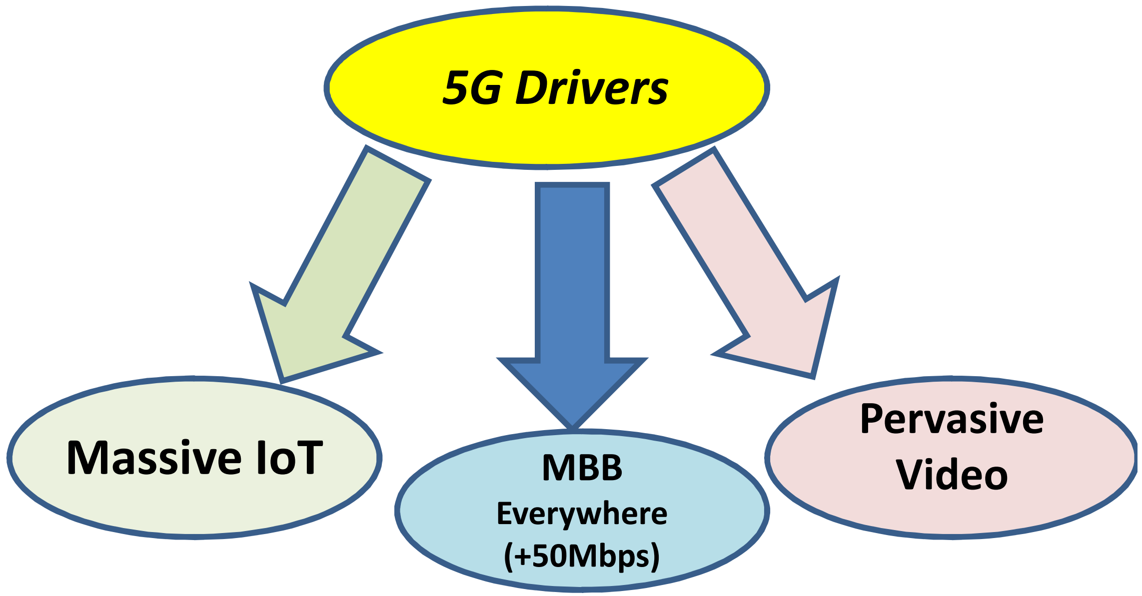
Agenda

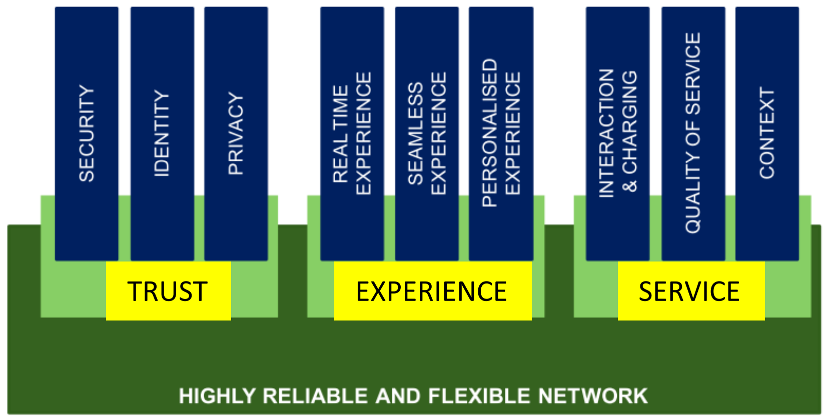
- 5G Drivers
- 5G-IoT Requirements
- Evolving from IP → ICN
- 5G Network Softwarization
- 5G-ICN Architecture
- LEAN CIBUS for 5G
- Unified ICN Protocol Proposal
- VSER Platform
- ICN-IoT Prototyping

5G Drivers

Requirements have been set in [1]

- **Heterogeneous Devices** and Applications
  - Traditional and Emerging IoT (M2M))
- **Enable Service Centric Networking**
  - Allow new Business Models
  - XaaS (Naas/SaaS/PaaS)
  - Not only Connectivity Services
  - **Service Platform for Users and ASPs**
  - **Personalized and Contextualized**
- **Low end-to-end Latency**
  - 1-10ms depending on the application
- **High Capacity and Data Rate**
  - >1000x Capacity, >10-100x Bandwidth
- **High Reliability**
  - Security, Mobility, Disaster Scenarios





5G Value Creation Capabilities

[1] NGMN White Paper on 5G:
https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

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5G-IoT Requirements [1]

- **Low-Cost/Long-Range/Low-Power as well as Broadband MTC**
  - Smart Weareables
    - Key Challenge is overall **management of the number of devices as well as data and applications**.
  - Sensor Networks
    - Low-Cost/High battery life requirement
    - Light weight networking/applications
  - Mobile video Surveillance
    - High degree of Mobility
- **Many other IoT related classes of applications identified**
  - Extreme Real-time Communications
    - Tactile Internet
  - Lifeline Communications
  - Ultra-Reliable Communications
    - Automated Traffic Control and Driving
    - Collaborative Robots
    - eHealth ; Remote Surgery…

[1] [1] NGMN White Paper on 5G:
https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

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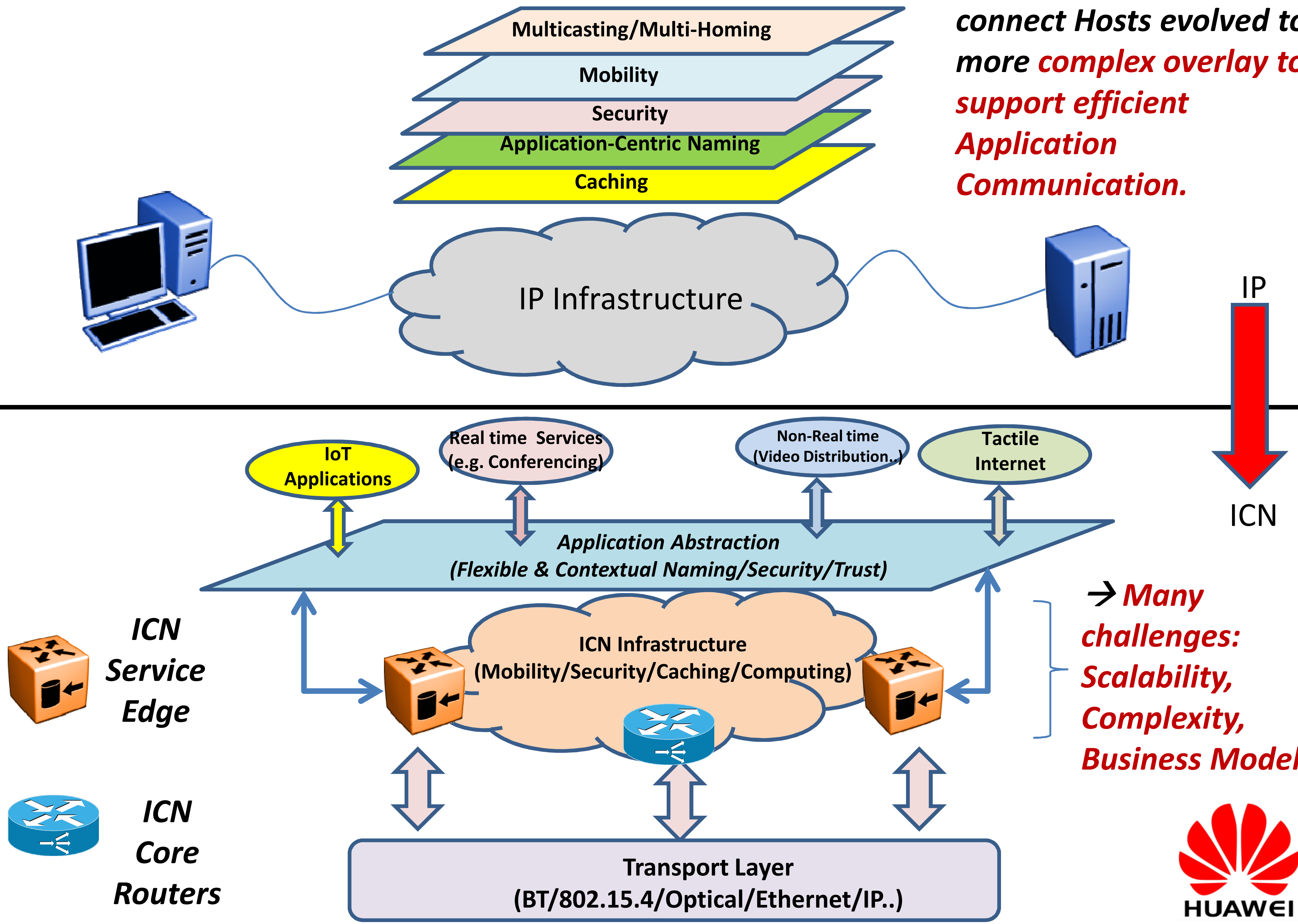
- Evolving from IP to ICN
- ICN for IoT

From Add-On to Build-In



→ *Original Internet to connect Hosts evolved to more complex overlay to support efficient Application Communication.*

→ *Many challenges: Scalability, Complexity, Business Model*

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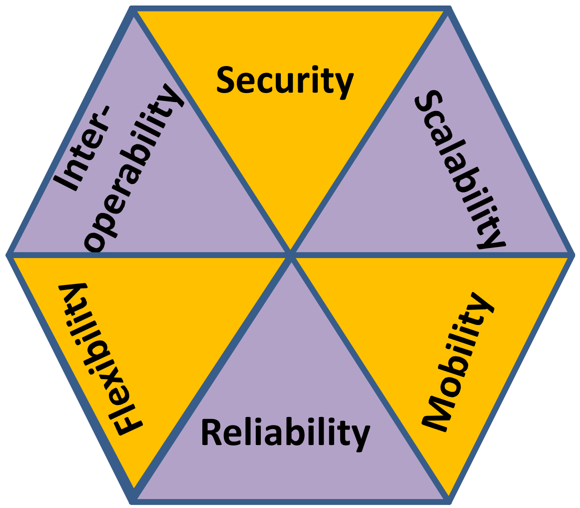
Why ICN Architecture is a Better Candidate for IoT [1] ?

- Inter-operability
  - Unified Naming: Content/Devices/Services; Application-Centric and Persistent
    - Hierarchical/Secure/Hybrid
  - Information/Device/Service/Content level Inter-operability
  - Enable Network layer based on "Name Abstraction", more suitable for IoT than "Host Abstraction"
  - Contextual Communication
- Security and Privacy
  - Packet based on Names enable Object Security
  - Security level is adaptive based on Trust requirements
- Scalability
  - ID/Locator Split, flexible communication either on ID or ID+Locator
  - Less host-based forwarding State in the Routers
- Flexibility
  - Communication Models (PULL/PUSH/PUB-SUB/Multicast/Anycast)
  - Flexible Packet Format (IoT + Infrastructure)
  - Self Organization
  - Adhoc and Infrastructure Mode
  - Hierarchical Processing
  - Resource Constraint
- Reliability
  - Caching/Storage Integral part of the design
  - Increases Data Availability improving IoT Service Reliability
- Mobility
  - Consumer mobility achieved from caching
  - Late binding allows Seamless Mobility
  - Handles Producer mobility (could be significant in IoT)

IoT Requirements



[1] "**Requirements and Challenges for IoT over ICN**", https://tools.ietf.org/html/draft-zhang-icnrg-icniot-requirements-00

Recent IoT Industry Stacks

AllJoyn Architecture (Qualcomm)

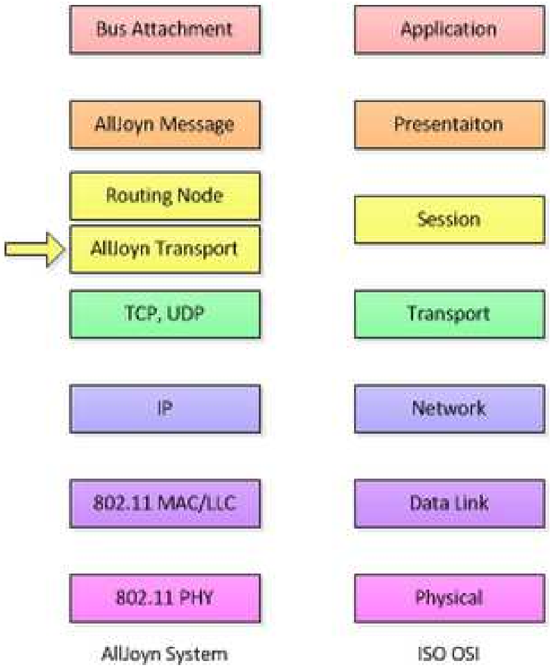
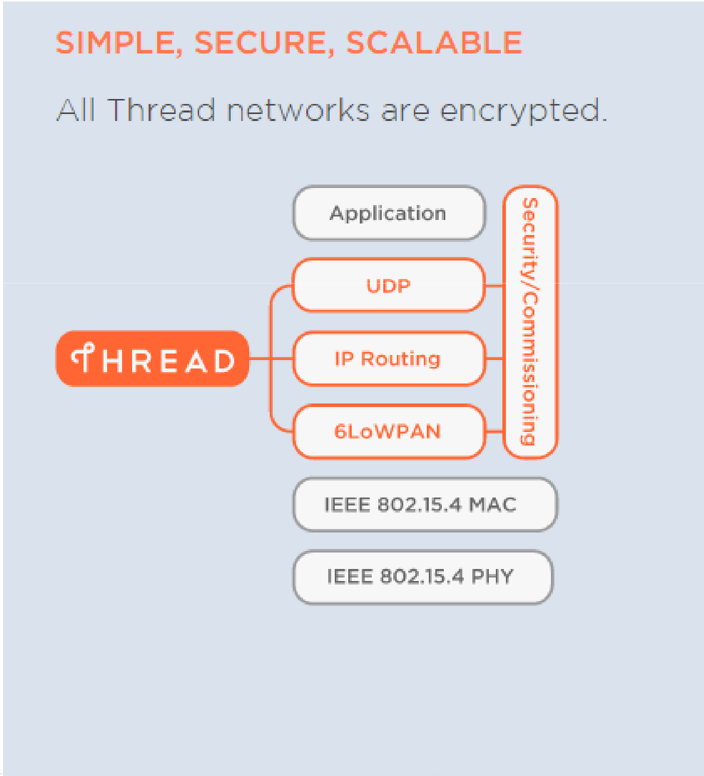
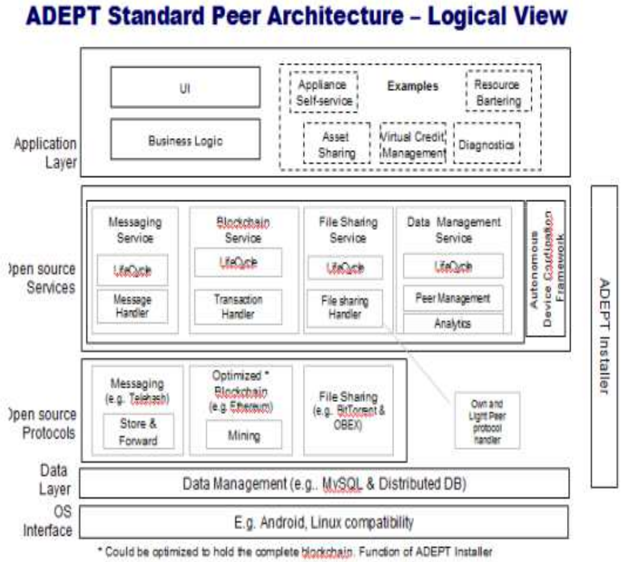


Figure: AllJoyn transport in the ISO/OSI 7-layer model

Thread Architecture (Google)



IBM ADEPT



[1] *Telehash (DHT), Blockchain, Ethereum, BitTorrent,*

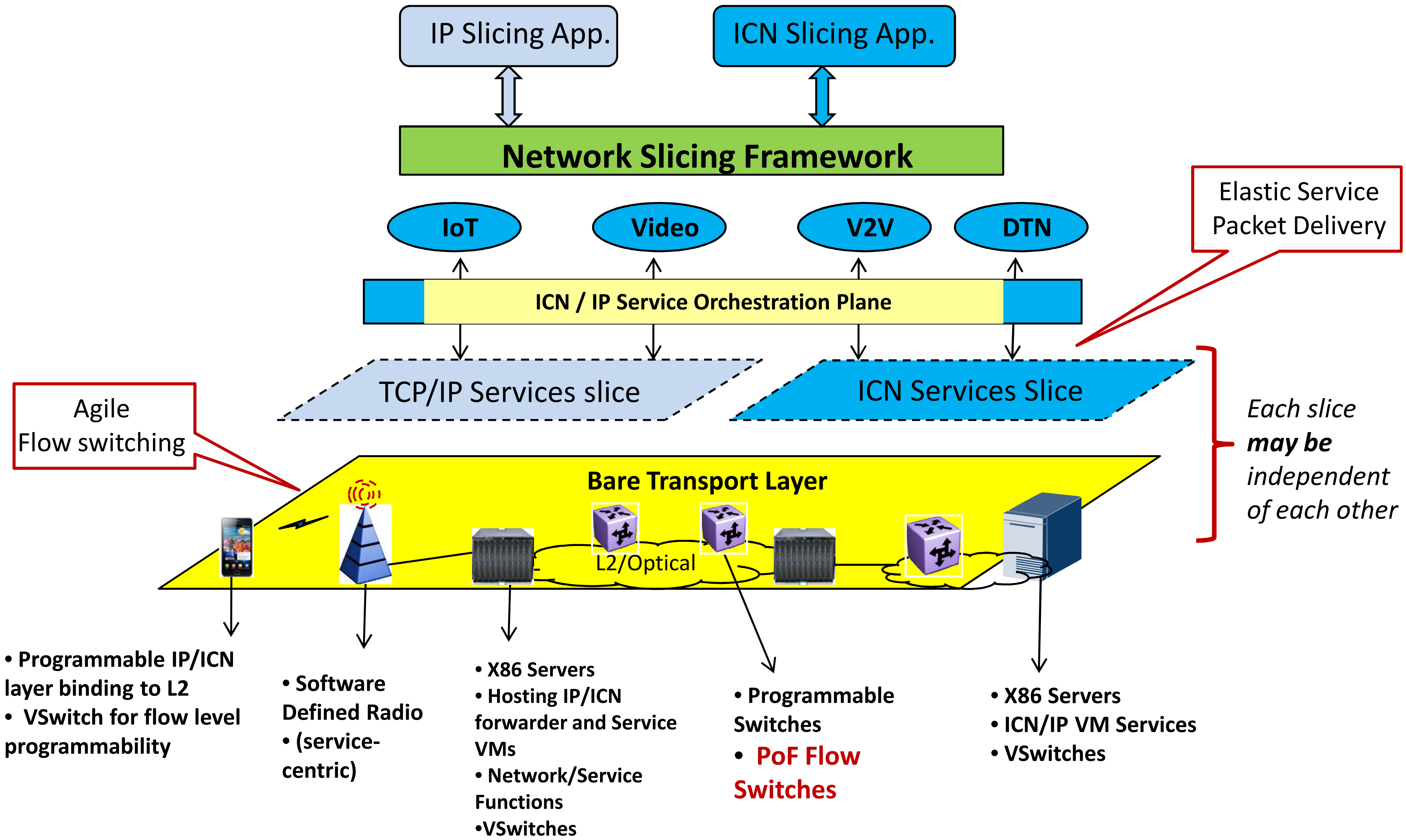
Architectures focuses on Naming, Discovery, D2D, Content Distribution, Secure Transactions, and Business Logic, which are subset of features offered by ICN.

Emerging IoT Architectures, reminder of the Pre-IP days. ICN encompasses all this and more (Multicasting/Mobility/Caching/Computing etc.)

[1] IBM ADEPT White Paper, https://archive.org/details/pdfy-esMcC00dKmdo53-_

- 5G Network Softwarization
- 5G-ICN Architecture

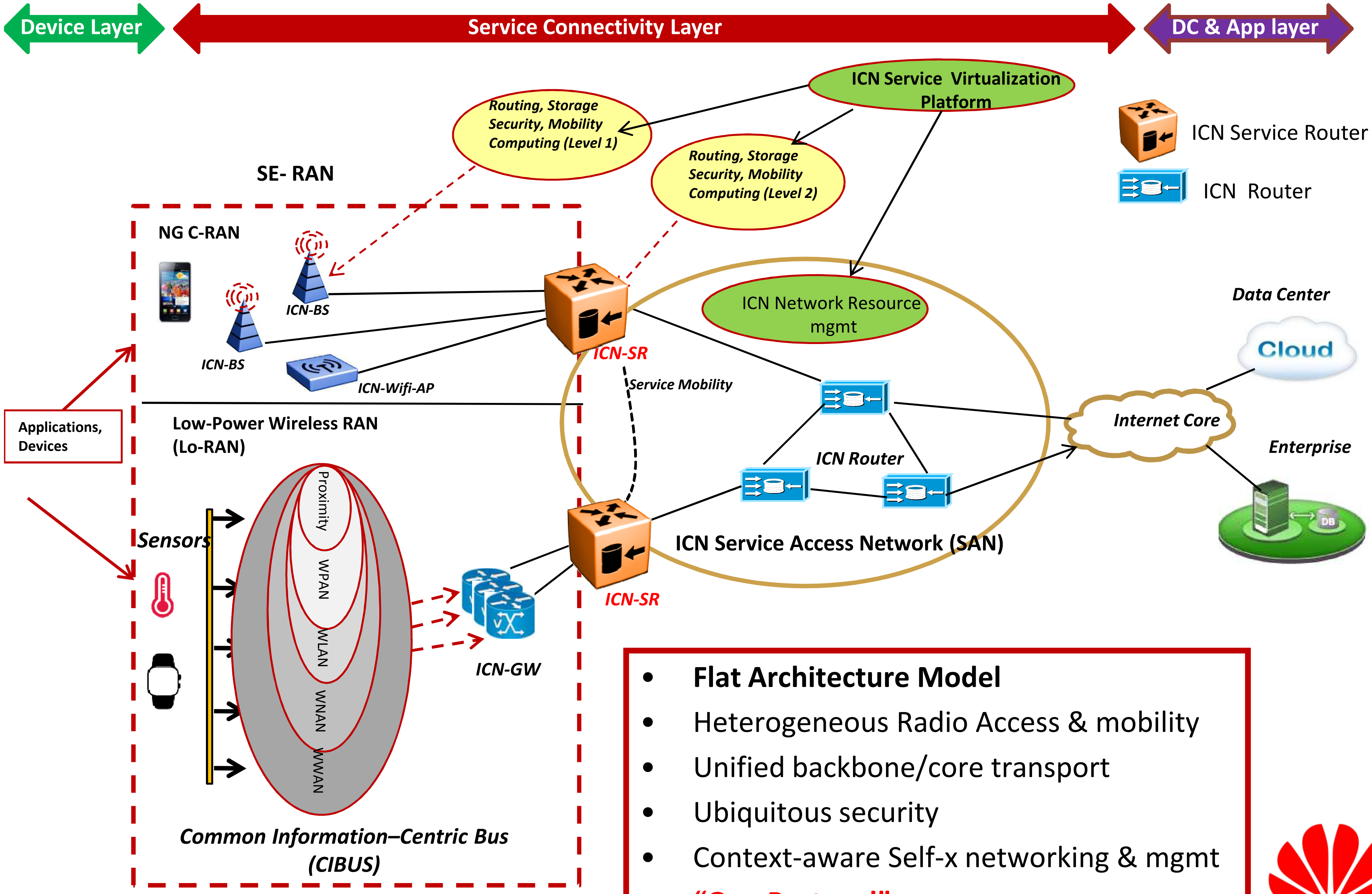
5G Network Softwarization Framework [1]



- The objective is to create elastic ICN/IP slices and its associated control/service plane on demand.
- Identified are also some of the end-to-end technology enablers

[1] ITU, FG, IMT 2020 – "Network Standardization Requirement for 5G"

SE-RAN & ICN-SAN: Service-Enabled 5G Architecture
(ITU FG IMT-2020, 09/2015)



- **Flat Architecture Model**
- Heterogeneous Radio Access & mobility
- Unified backbone/core transport
- Ubiquitous security
- Context-aware Self-x networking & mgmt
- **"One Protocol"**

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SE-RAN Functional Features

- **NG C-RAN**
  - Flat Architecture and Heterogeneous Radio Access
  - **ICN Edge Cloud** Intelligence all the way to the BS and UE
  - **Distributed Routing, Storage/Caching, Computing, Mobility Functions**
  - Application/Services Binds to Names
  - **Name Based Routing/Forwarding**
  - Mobility/Migration
  - **Multi-homing/Multicasting**
  - **Data based Security and Trust** (Enforceable on the Infrastructure)
  - D2D/P2P/MP2MP
  - Adaptable and Service Centric (Low Latency, High Throughput etc.)
- **Common Information-Centric BUS (CIBUS)**
  - Addresses the need for next 50B IoT devices on 5G
  - Middleware over Constrained and Non-Constrained Devices
  - **Enables Self-X (Discovery, Routing, Service Point Attachment)**
  - **Contextualized Device/Service Discovery & Processing**
  - Heterogeneous Radios (WPAN,LORAN, WLAN etc.)
  - Local/Global Naming Service
  - Hierarchical Data Processing
  - **Security/Trust Management**
  - PUB/SUB System for Large scale Content Distribution
  - Open-APIs for Inter IoT system connectivity

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ICN Service Access Network (ICN-SAN)

- **ICN Service Enabled Network Infrastructure**
  - ICN Service Edge Routers
    - Host Arbitrary Service Functions
    - Caching/Storage/Computing features
  - ICN Routers focusing on High Performance Routing/Forwarding
- **Service Virtualization Platform**
  - ICN-Centric Network Slicing/Virtualization and Resource Management
  - Fine Grained Cache/Compute/Bandwidth/Spectrum Resource Management for end-to-end Service Delivery
  - ICN based Network Abstraction
    - Software-Defined Name Based Routing
  - Opportunistic Placement of Service Functions and Inter-Connection to Adapt to varying user behavior and dynamics
  - Service Orchestration involving UE, Servers and VSERs, E-NodeB (end-to-end)

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LEAN CIBUS for 5G

- *Light Weight*
- *Elastic*
- *Agile*
- *Networking*

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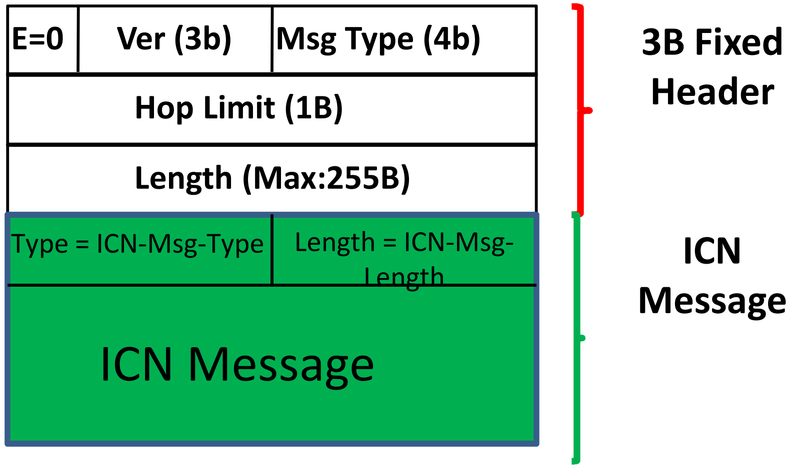
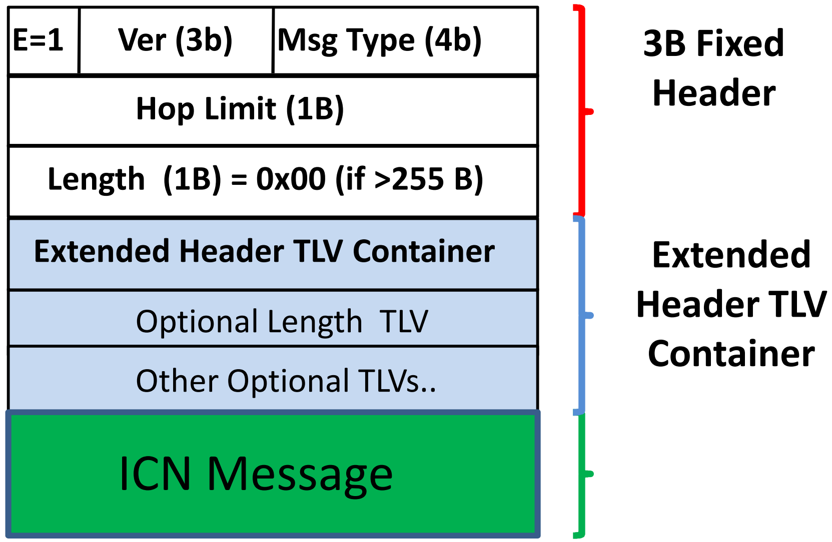
Elastic PDU TLV format (Under Discussion): For IoT and Large MTUs

- "draft-ravi-elastic-icn-packet-format-00", IETF/ICRG Draft

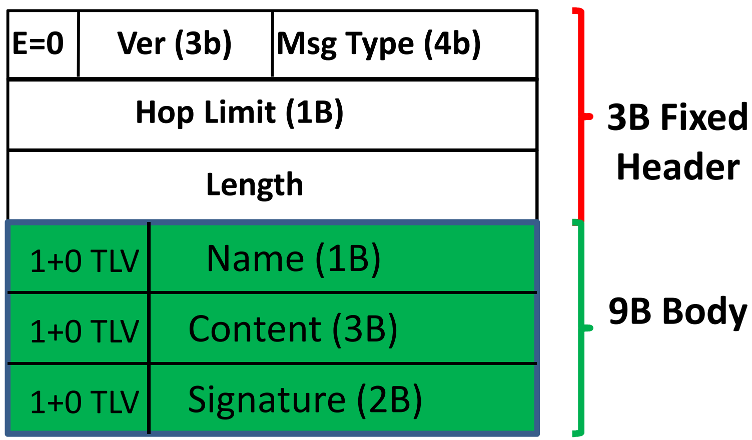


IoT Friendly



High Capacity Transport Friendly

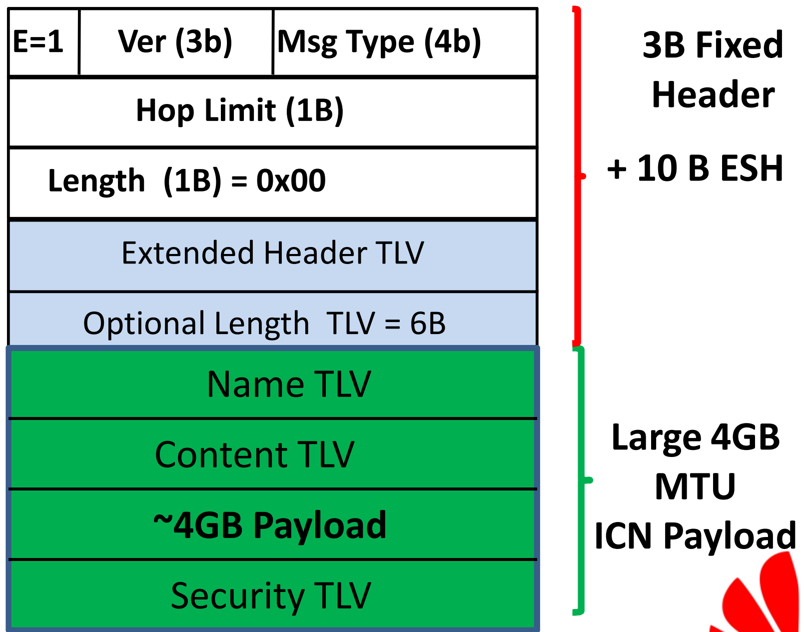
e.g. SigFox Cellular [1] Technology (12B Payload)



..Compare to 20/40B fixed IPv4/v6 header

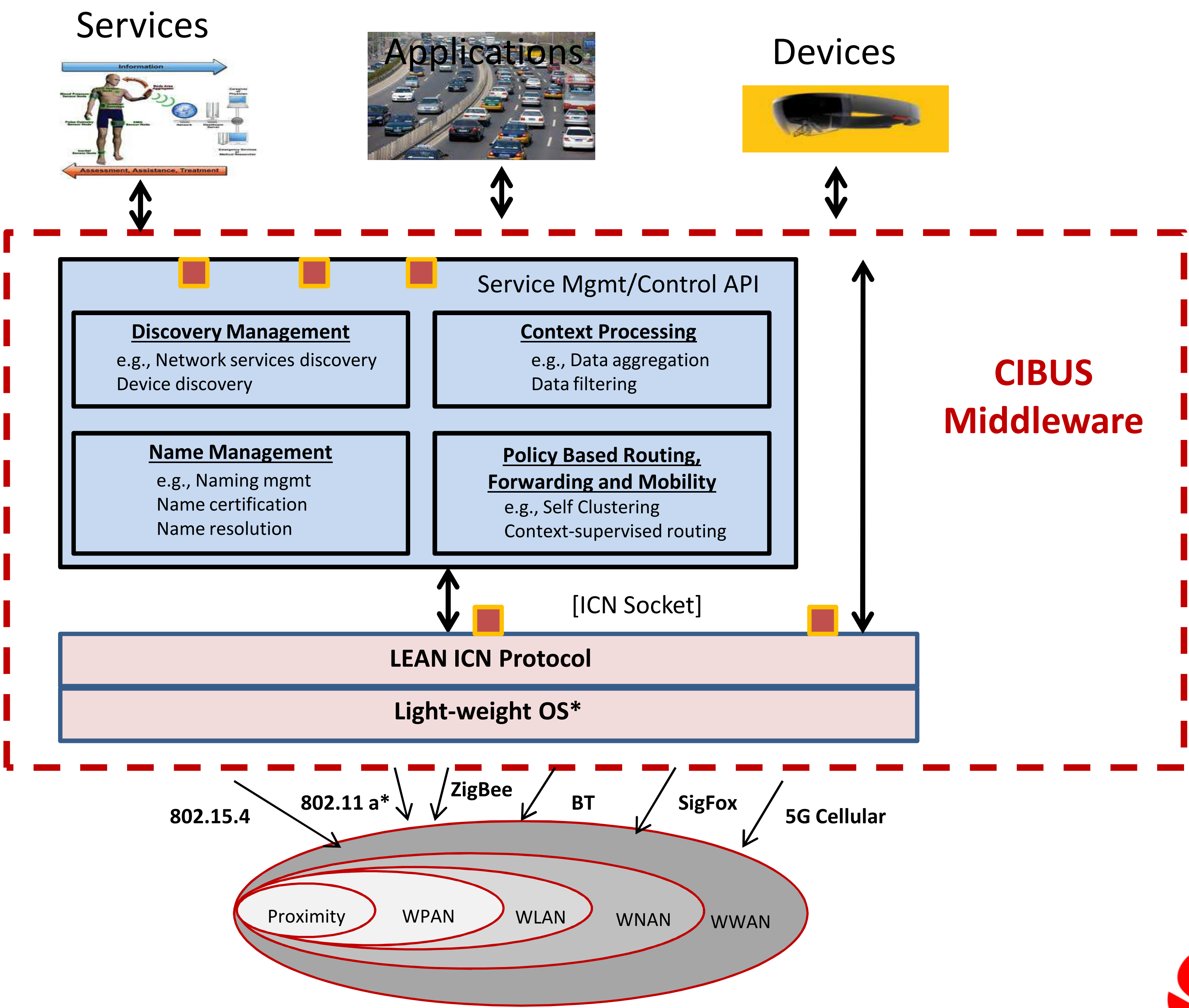
[1] http://www.sigfox.com/en/#!/

e.g. 4GB ICN Content Object



Variable Payload length Type can allow GB/TB size Payload feasibility

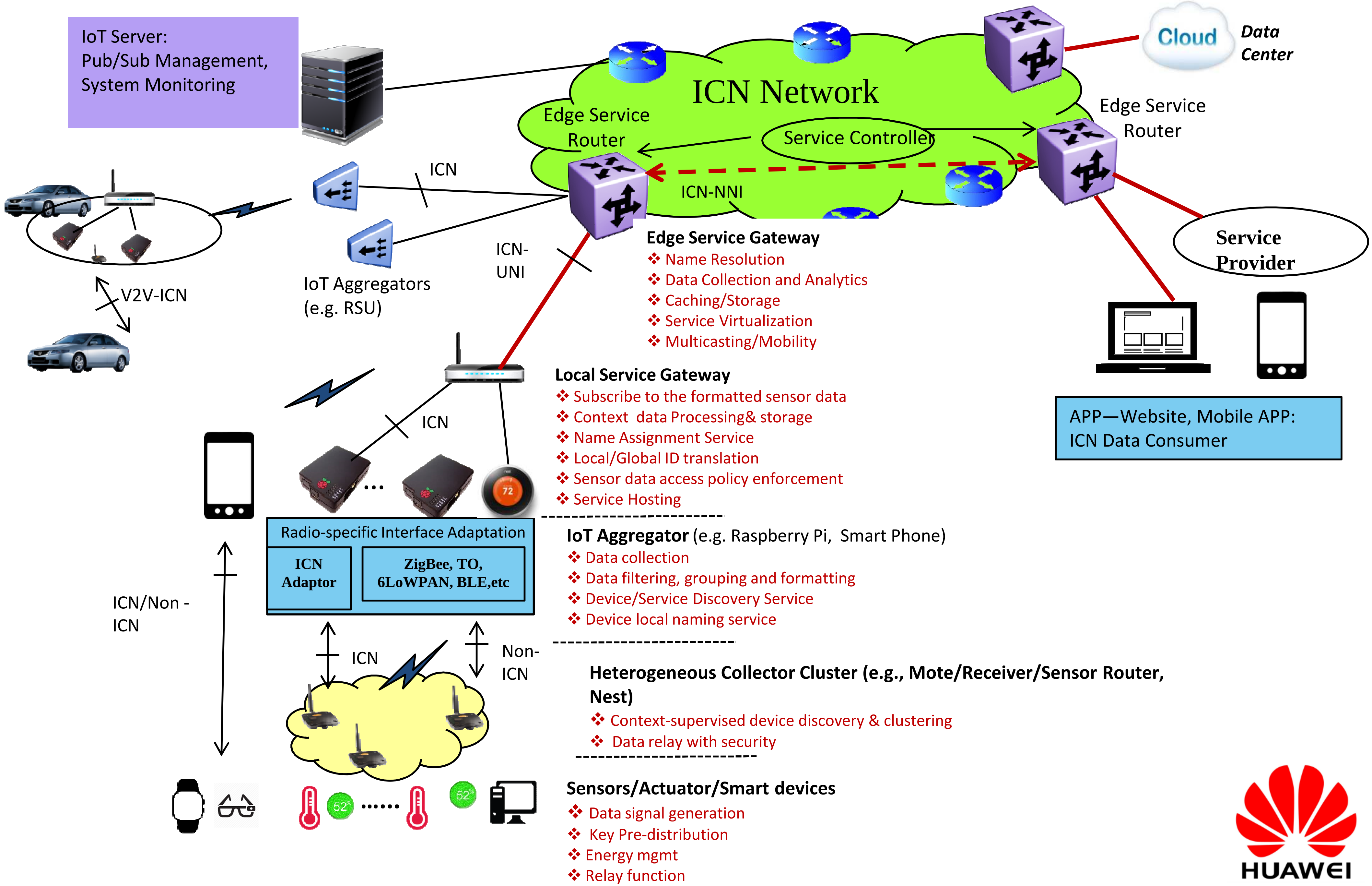
Common Information-Centric BUS (CIBUS) for IoT



Lean ICN stack with Middleware for Embedded Systems.

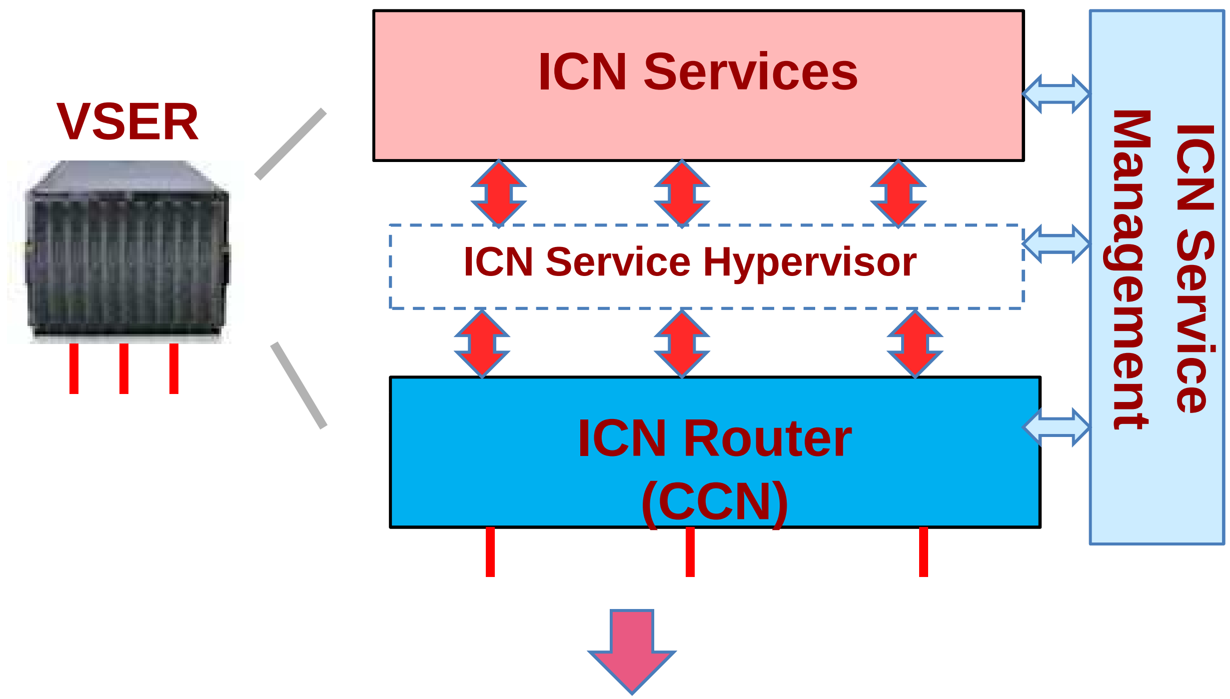
ICN-IoT Middleware Architecture: Distribution of Functions

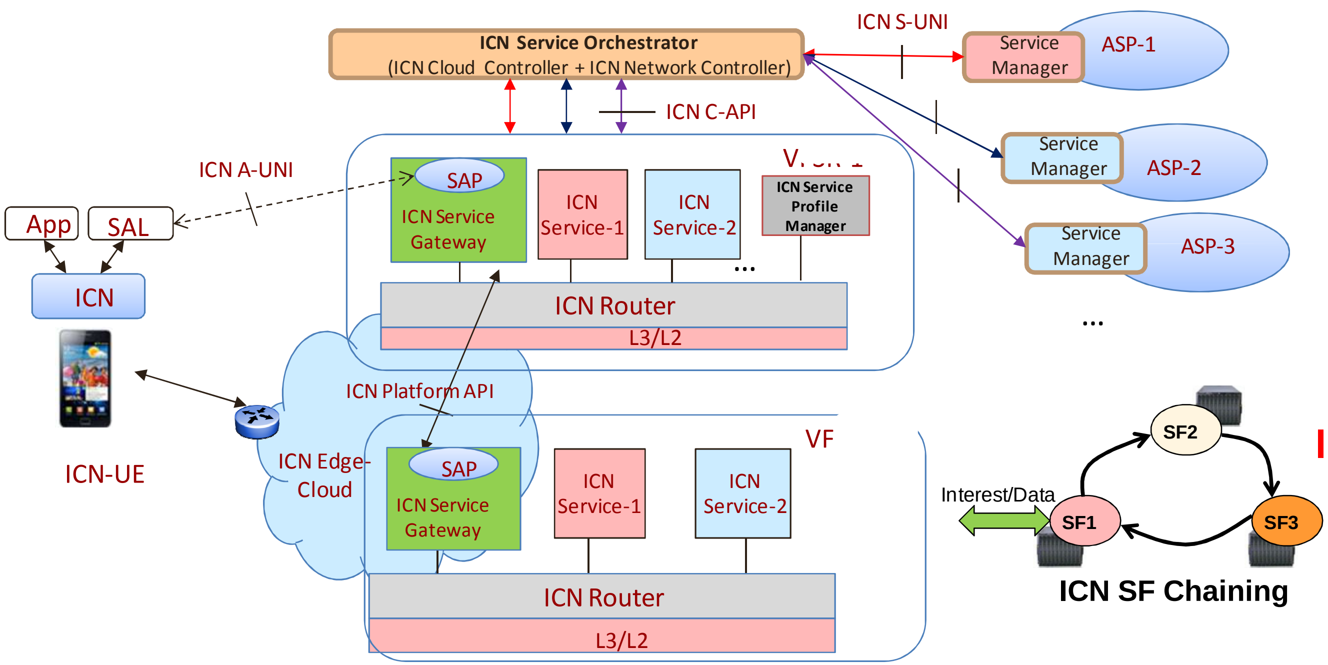
(IRTF/ICNRG draft, 08/2015, “draft-zhang-icn-iot-architecture-00”)



Virtual Service Edge Router Platform (VSER) and ICN-IoT Prototyping

VSER: Virtual Service Edge Router



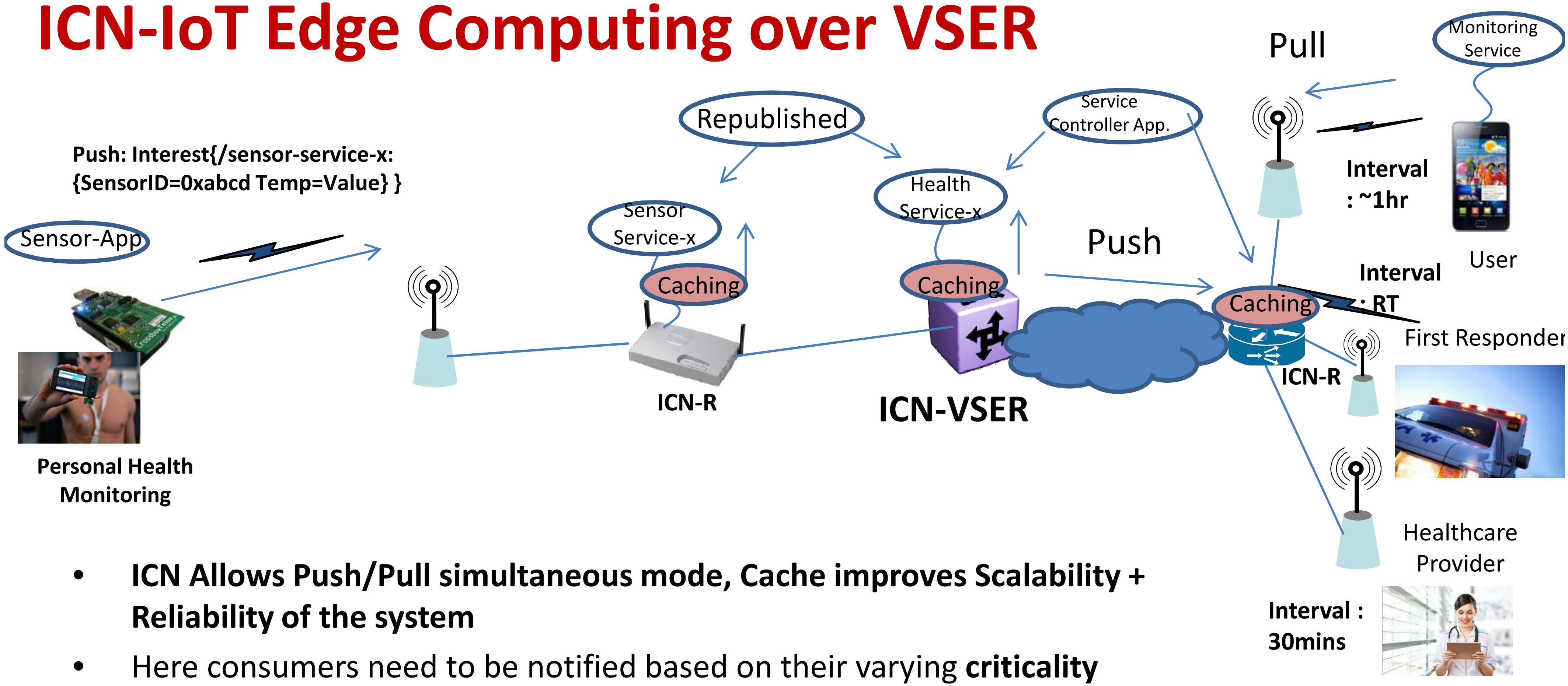


VSER Platform Highlights

- ICN Service Edge Virtualization
- ICN *Service Function* Life Cycle Orchestration and Management (by OpenStack and FloodLight.)
- Service Function Chaining
- Service Discovery, Service Contextualization.
- PULL/PUSH, MP-to-MP communication
- Unified control functions interworking with SDN/NFV
- "White box" Platform
- IP/ICN Dual-mode forwarding
- Optimized software stack including Multi-threaded CCNx.

[1] Asit Chakraborti et al, " **A Scalable Conferencing framework over ICN Based VSER Platform**", ICN, Sigcomm, 2015
[2] Ravi Ravindran et al, "**Towards Software Defined ICN Based Edge Cloud Services**" IEEE, CloudNet, 2013
[3] P. Talebifard, R. Ravindran et al, "**An Information Centric Networking Approach Towards Contextualized Edge Service** ", IEEE, CCNC, 2015

ICN-IoT Edge Computing over VSER



- **ICN Allows Push/Pull simultaneous mode, Cache improves Scalability + Reliability of the system**
- Here consumers need to be notified based on their varying **criticality**
  - E.g. User/First-Responder/Healthcare Provider
- **Less critical consumers** can rely on cache while **more critical consumers** rely on notification.
- Notifications lost cannot be reproduced, cache helps from this perspective too.
- Increases the Scalability + Reliability of the IoT system.
- There are challenges, on how to learn names of dynamic content [1], and save overhead of updates when notifications are at different intervals.

[1] Jerome Francois et al, "**CCN Traffic Optimization for IoT**". https://hal.inria.fr/hal-00922728

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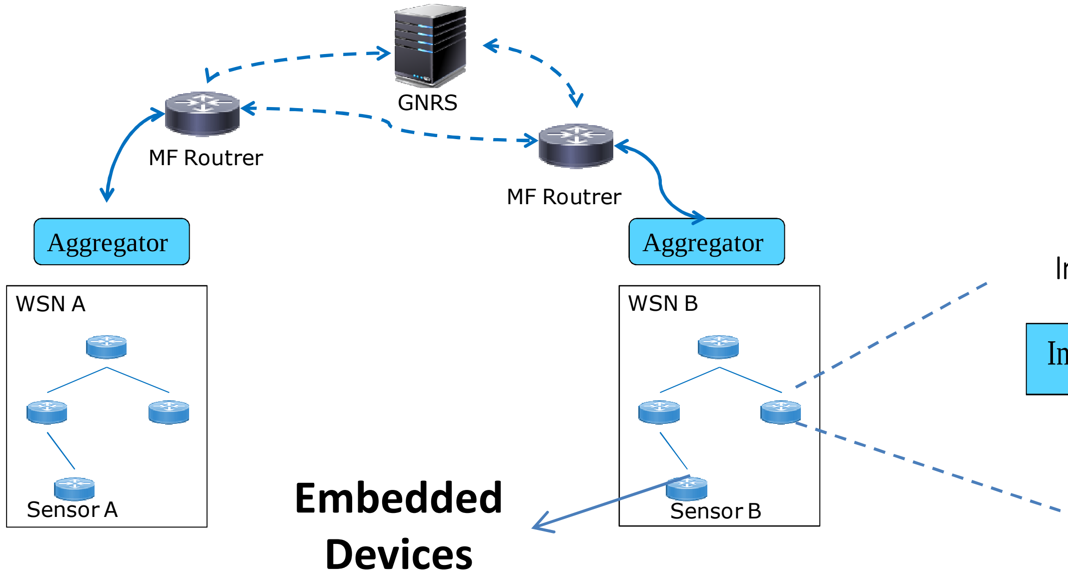
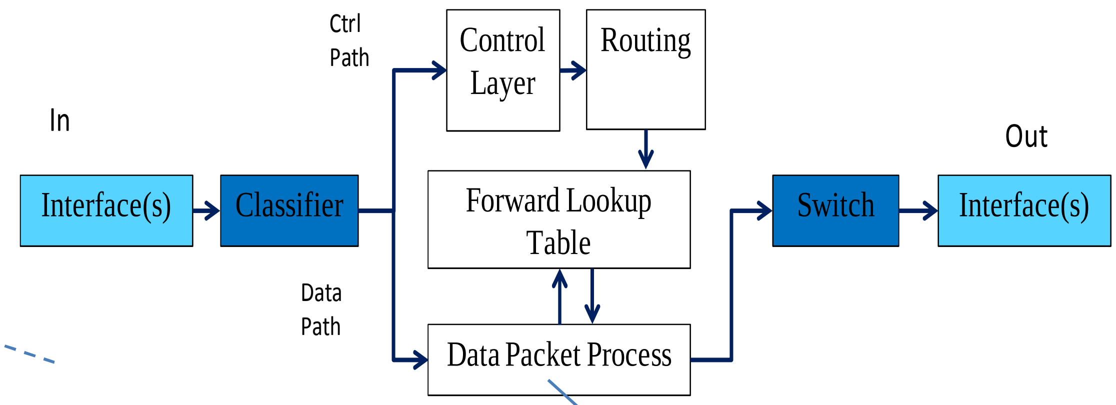
MF-Lite for ICN-IoT



MF-Lite Forwarder



- Support basic Service Type Processing
- Push/Pull

0 1 2 3 4 Octet

Version (4bits)	Pkt Type (4bits)	Service Type (4 bits)	Protocol (4 bits)	TTL	Reserved
Source ID				Destination ID	
. Payload .					

- **Objective here to realize some of the ICN-IoT middleware on embedded devices over 802.15.4 Radio**
- **Naming and Secure Content Push/Multi-Hop/PUSH/PULL**
- **Over SAM-R21 Boards as Relay as well as Sensor Nodes**

[1] Li, S., Zhang, Y., Raychaudhuri, D., Ravindran, R., Zheng, Q., Wang, GQ., and L. Dong, **"IoT Middleware over Information-Centric Network", Global Communications Conference (GLOBECOM) ICN Workshop, 2015.**

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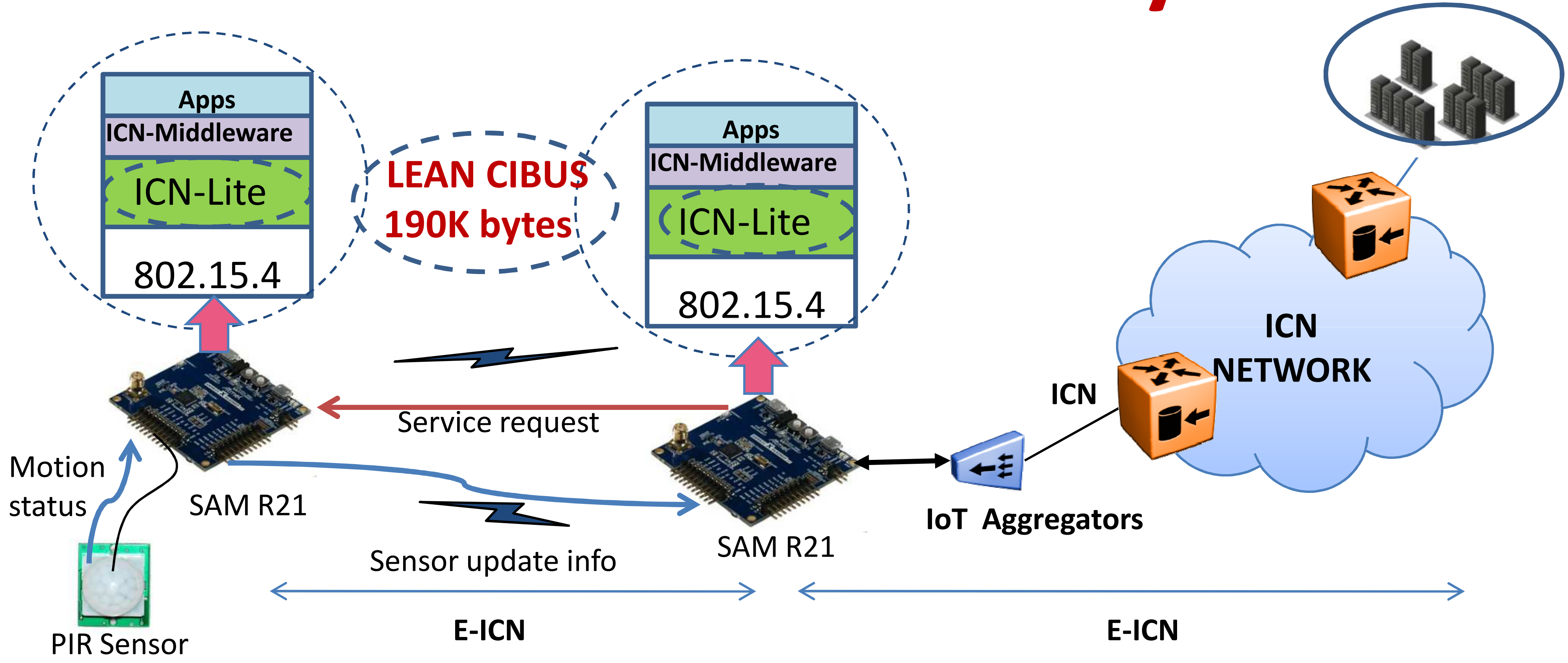
ICN-IoT over Embedded Systems



- Zero-conf Device-to-Device interaction over ICN using Elastic ICN implementation
- Build considering End-to-End E-ICN, No Protocol Gateways
- Supports Application-centric Naming , Routing, Multicasting, and In-Network Computing
- Platform: RIOT OS and CCN-lite
- **Boards: Sam R21 with 256K bytes ROM, 32K bytes RAM ~ current footprint for CCN-lite+ App ~ 29KB**
- Sensor: PIR motion detect sensor

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Conclusions

- A fully programmable 5G infrastructure could allow operation of ICN-IoT technology
- ICN offers a natural service-centric platform to enable end-to-end Service Virtualization.
- IoT applications are information-centric, hence benefits from several ICN features.
- 5G SE-RAN proposal integrates traditional smart devices with CIBUS enabling connectivity and self-organization to all the IoT devices.
- Collaborative research with Winlab on ICN-IoT middleware with focus on architecture design, research and system prototyping.

Thank You..and

5G and Beyond

Sonia Heemstra de Groot

Netwerkdag
SURF
3 November 2016

CWTe
Centre for Wireless Technology Eindhoven

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

WHERE ARE WE NOW?

Where are we now? Mobile networks- 4G

LTE, LTE Advanced

- **Faster broadband**
- **Higher capacity**
  - OFDM/SC-FDMA
  - Flexible support for wider channels (up to 100 MHz)
  - More antennas (MIMO)
  - Channel aggregation for higher data rates
- **Peak data rate**
  - 300+ Mbps/75 Mbps (LTE)
  - 1Gbps/500Mbps (LTE advanced)
- **Low latencies**
- **Simplified core network (All IP)**

Where are we now? WLAN - WiFi

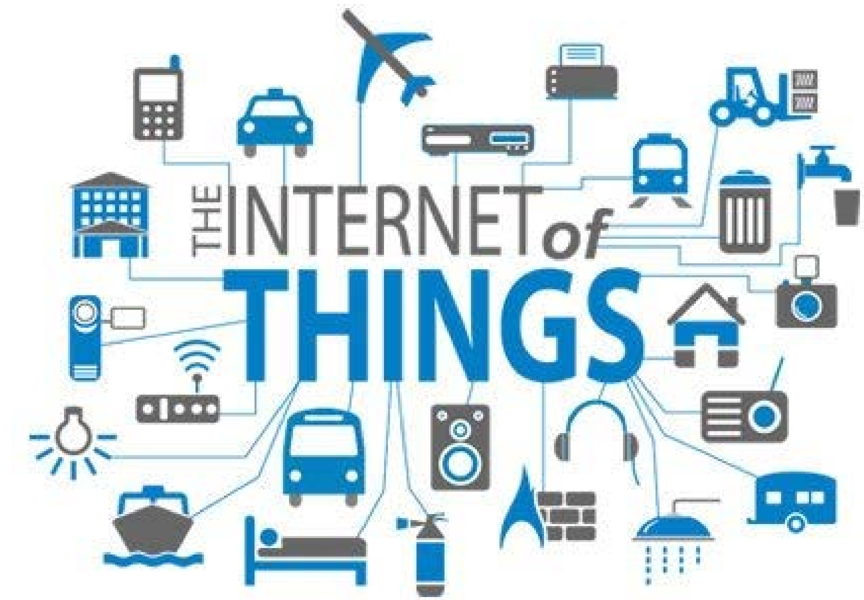
- IEEE802.11/a/b/g/n/ac
  - 2.4GHz and 5GHz
  - ac: MU-MIMO-OFDM
    up to 1.69 Gbps/stream (160 MHz, 8 antennas/AP, 2/STA)
- IEEE802.11ad
  - 60 GHz
  - Up to 6.75 Gbps/stream
- IEEE802.11p
  - Optimized for Car 2X communication - ITS
  - 5.9 GHz

Where are we now? Evolution towards IoT

- **Short range**

ZigBee®

4.0 Bluetooth®



- **Long range low power**

SIGFOX™

LoRa™

6LoWPAN
IPv6-based Low-power Wireless Personal Area Networks

2G 3G

IEEE802.11ah HaLow

Where would we like to go?

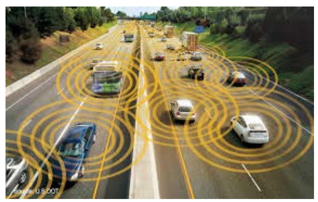
Broadband multimedia messaging

Extreme HD video steaming

Holographic watch

Haptic holography

Virtual teleportation

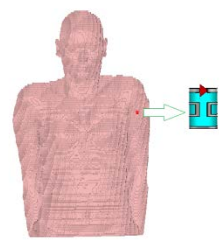


Autonomous driving

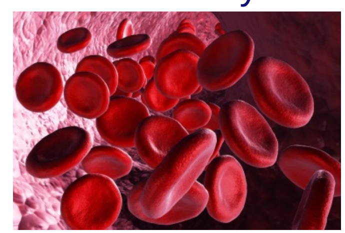
Fully autonomous vehicles

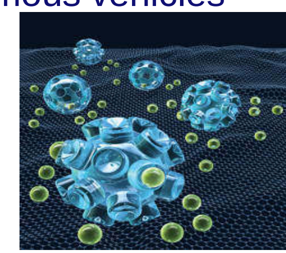
Connected vehicles

Internet of everything

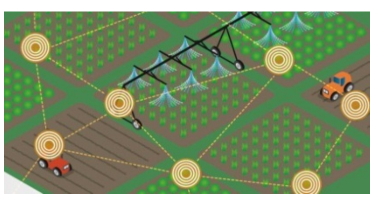


Implantable antenna





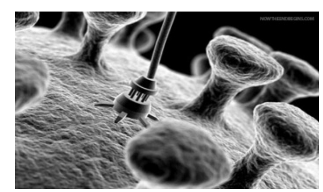
Nano IoT



Smart farming

Implantable wearables

In body networks

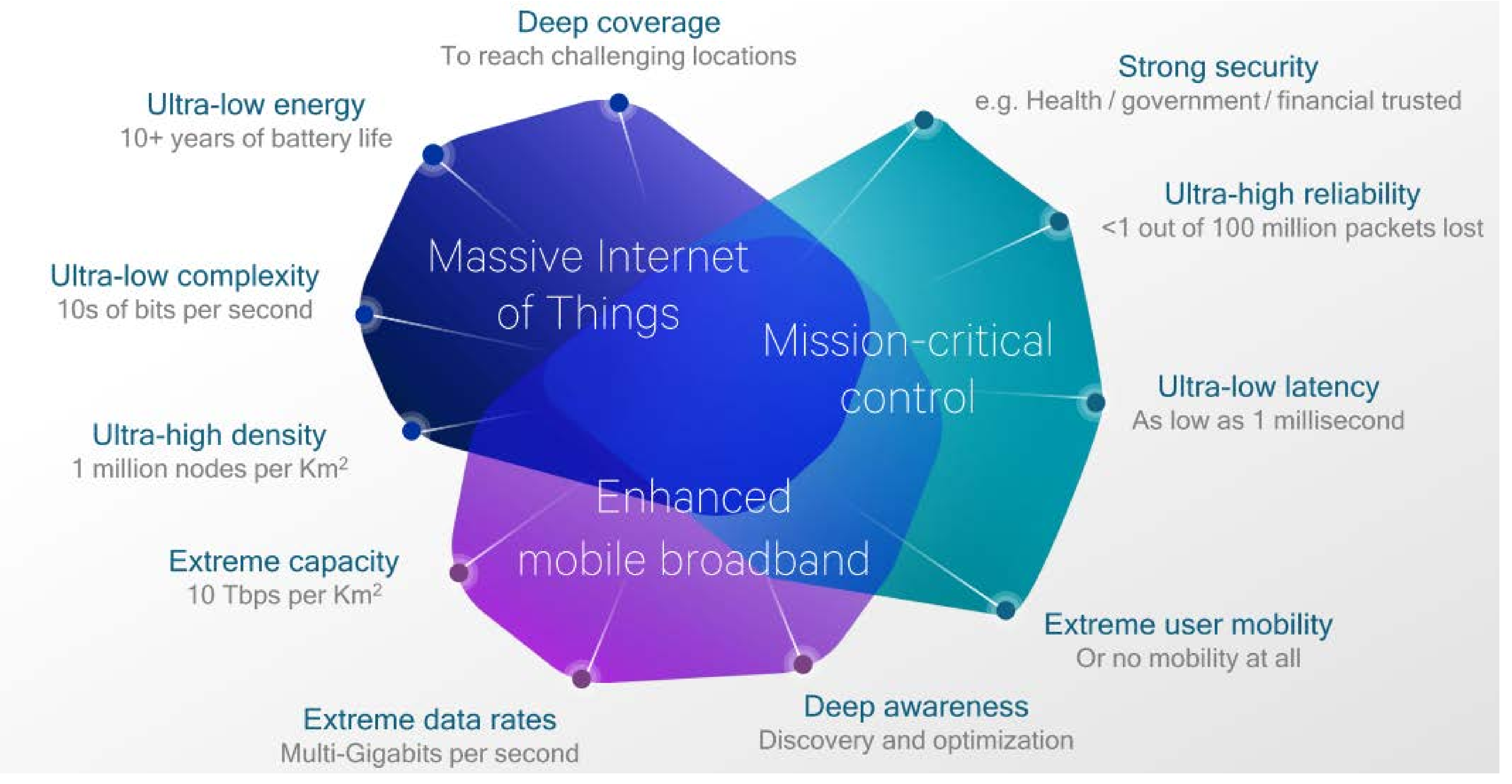


Nano swarms

2016 2020 2024 2028 2030 2034

Next Step 5G
REQUIREMENTS

Extreme variation of requirements*



*From Qualcomm Technologies, Inc. February 2016

Unified spectrum

Sub GHz: Long range massive IoT

1GHz to 6GHz: Wider bandwidth for enhanced mobile BB and mission critical

Above 6GHz. mmwave: Extreme bandwidth, shorter range extreme broadband

5G
CHALLENGES

Multiple challenges

- Exploding traffic volume
- Random and diverse traffic
- Explosive growth of connected devices
- Control plane load (IoT, IoE)
- Low cost
- Energy efficiency

5G
TECHNOLOGIES

Timeline for 5G

2020 — Using spectrum allocated in WRC 2015 below 6GHz

2025 — Adding spectrum allocated in WRC 2019 above 6GHz

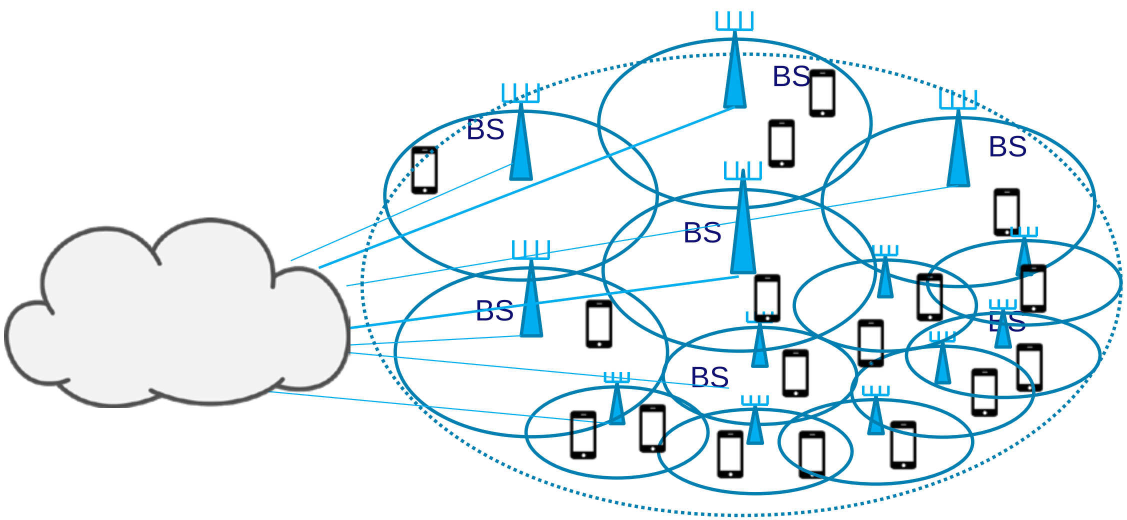
2030 — New generation

CWTe Centre for Wireless Technology Eindhoven

TU/e Technische Universiteit Eindhoven University of Technology

5G Key technological components - Network

- **Ultra Dense Heterogeneous Networks**
  - **Macro cells combined with**
  - **Small cells: picocells and femtocells**
    increase of spectral efficiency, improved coverage, reduction of transmit power



5G Key technological components - Network

- **Ultra Dense Heterogeneous Networks**
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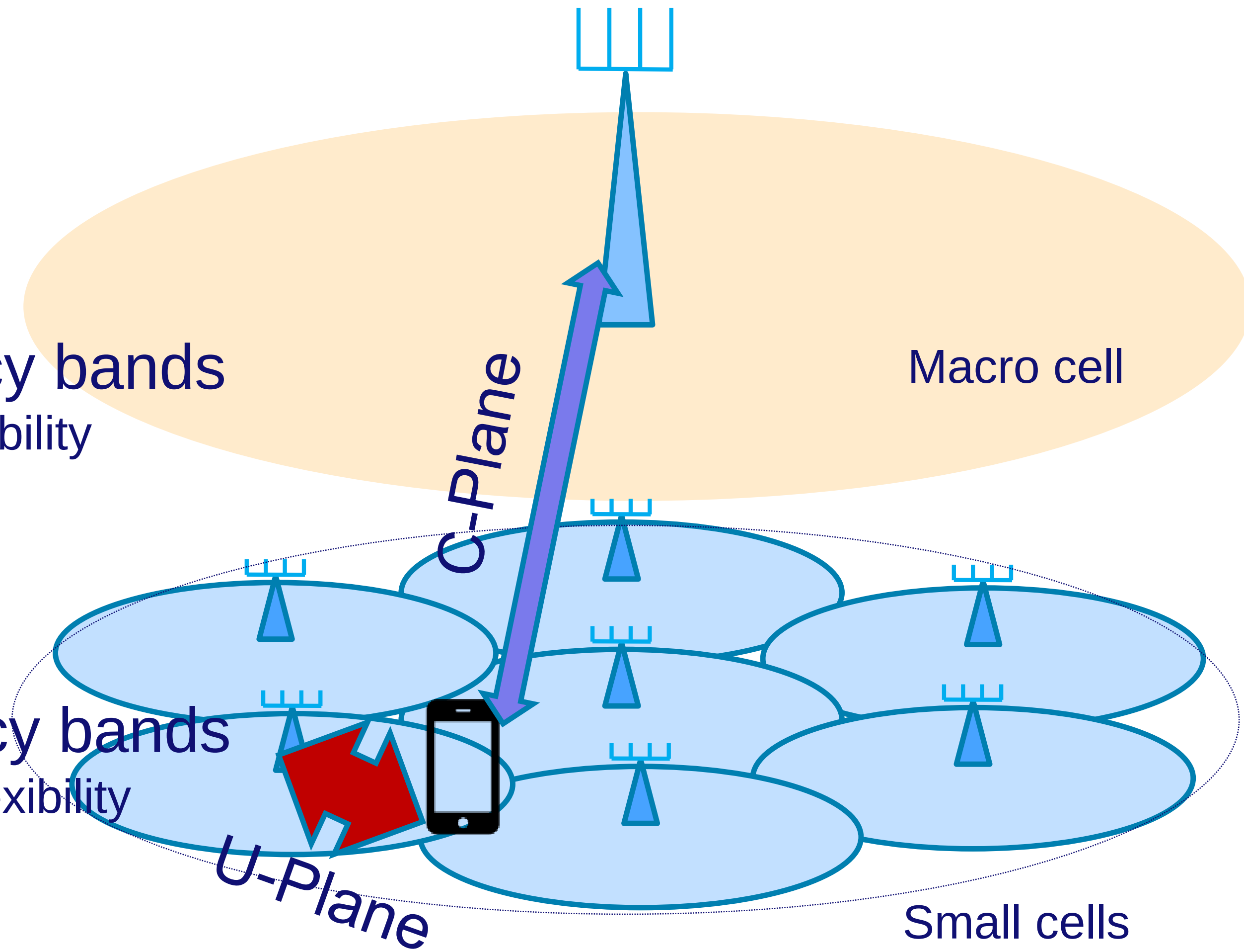
  - **Separation of data and control planes**

    connectivity with two BS: macro for control, small cell for transport

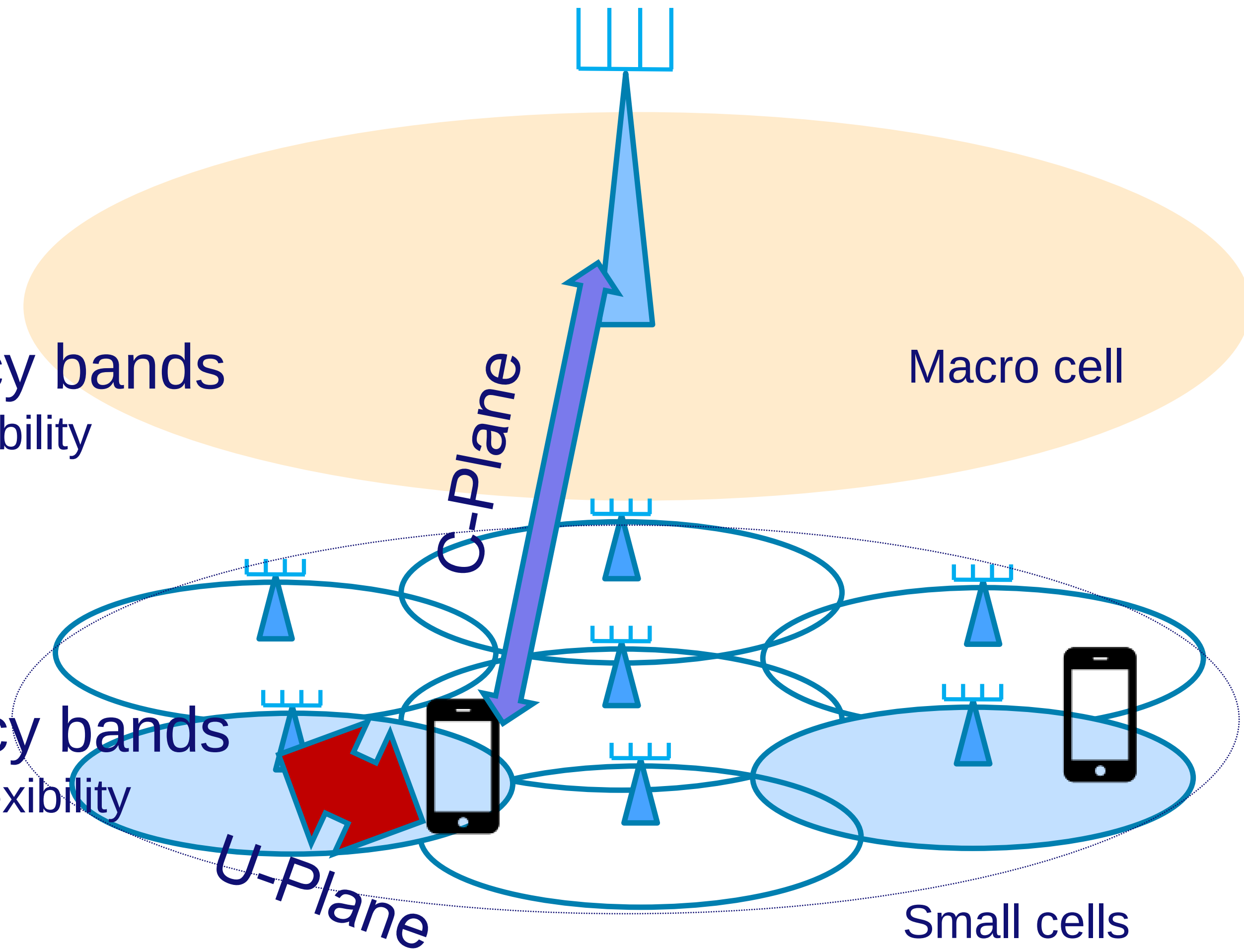
C/U Plane split

Lower frequency bands
Connectivity and mobility

Higher frequency bands
Higher data rate + flexibility



C/U Plane split



Lower frequency bands
Connectivity and mobility

Higher frequency bands
Higher data rate + flexibility

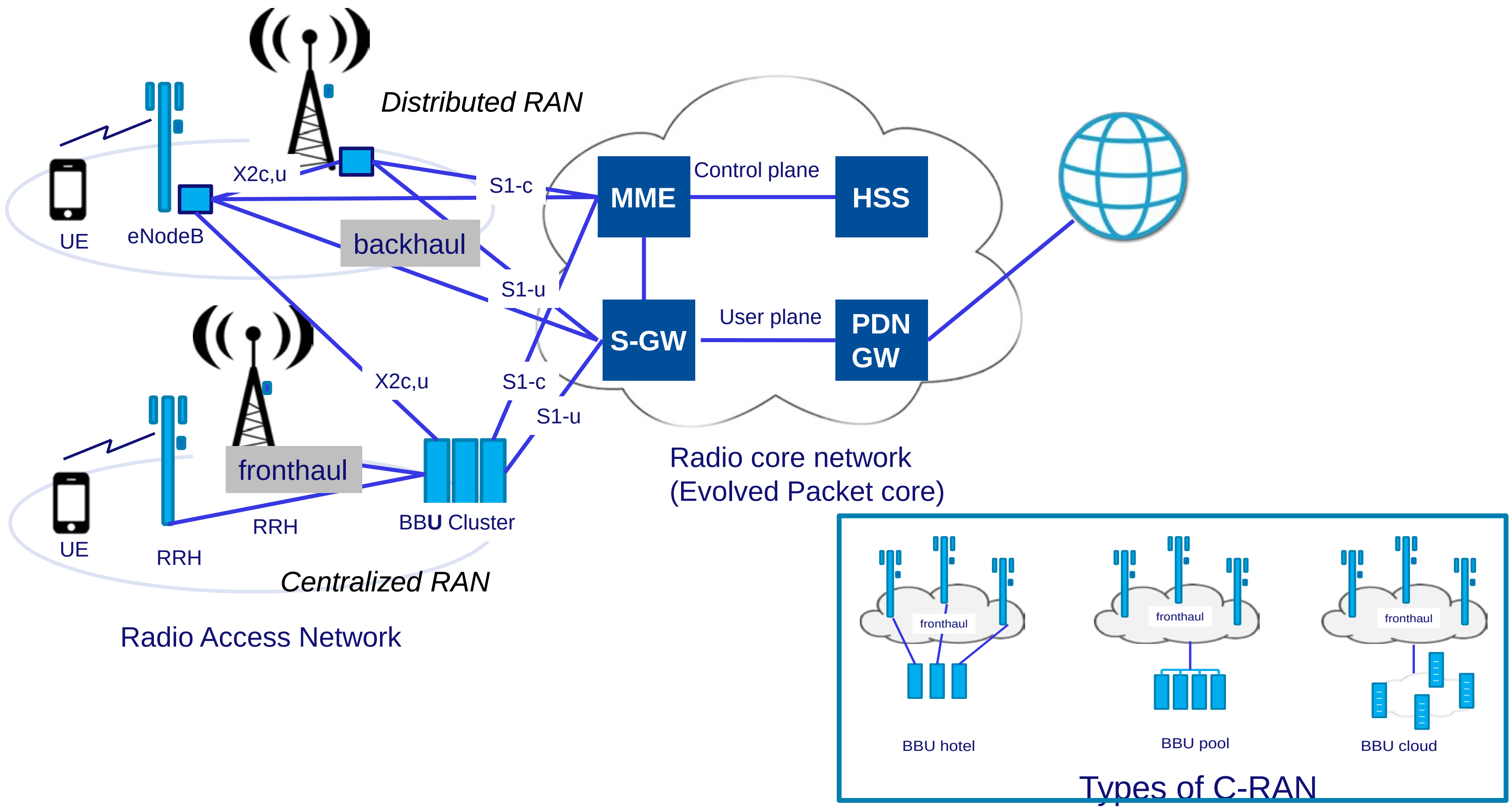
Energy efficiency: Switching cells on/off according to the demand

5G Key technological components - Network

- **Ultra Dense Heterogeneous Networks**
  - **Macro cells combined with**
  - **Small cells: picocells and femtocells**
    increase of spectral efficiency, improved coverage, reduction of transmit power
  - **Separation of data and control planes**
    connectivity with two BS: macro for control, small cell for transport
  - **Multiple radio-access technologies**
  - **Device-to-device communication (D2D)**

5G Key technological components - Network

- **Cloud or Centralized RAN (C-RAN)**

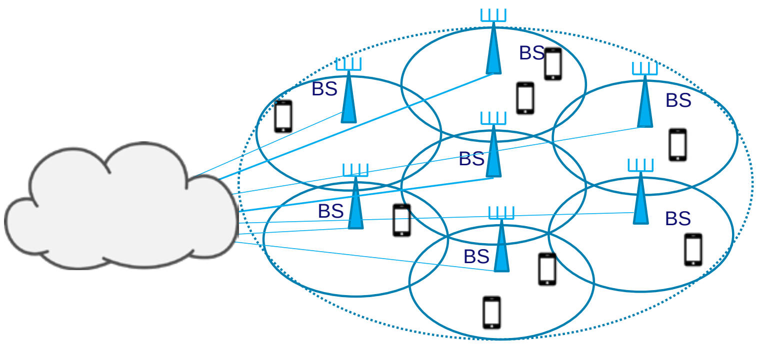


5G Key technological components - Network

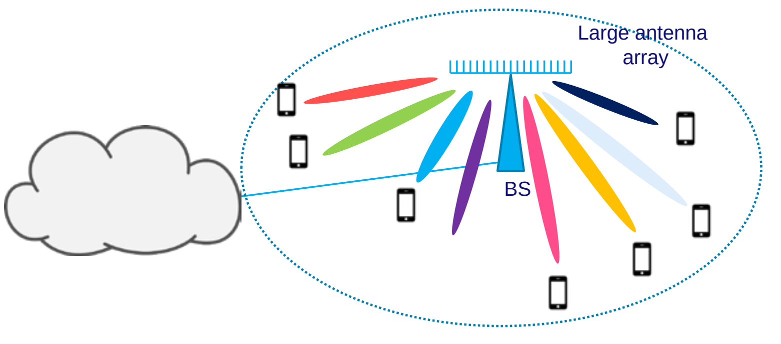
- **Cloud or Centralized RAN (C-RAN)**
  - OPEX and CAPEX benefits
  - Simplified implementation of advanced radio transmission techniques that require inter-cell cooperation
  - Sharing of processing capacity among multiple antenna sites
- **Software Defined (Cellular) Networks**
  - Virtualization - NFV
  - Directly programmable architecture

5G Key technological components - Radio

- **Massive MIMO**
  - Extension to traditional MIMO utilizing a very large number of antennas and spatial multiplexing
  - Several spatial streams
  - Dramatic increase of capacity and improved radiated energy-efficiency



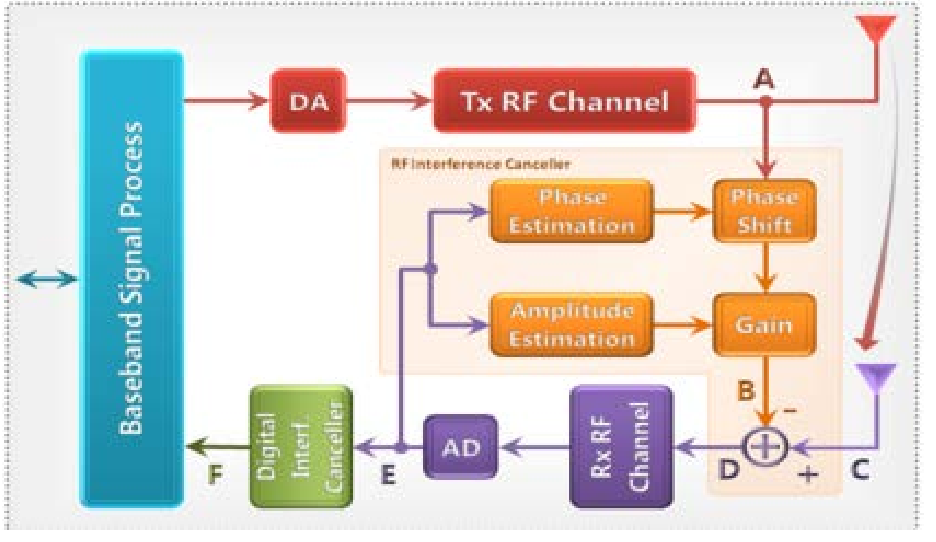
Small cells



Massive MIMO

5G Key technological components - Radio

- **Full duplex**
  - Simultaneous receptions and transmission
  - Doubling spectral efficiency
  - Self-interference cancellation – 120 dB for outdoor

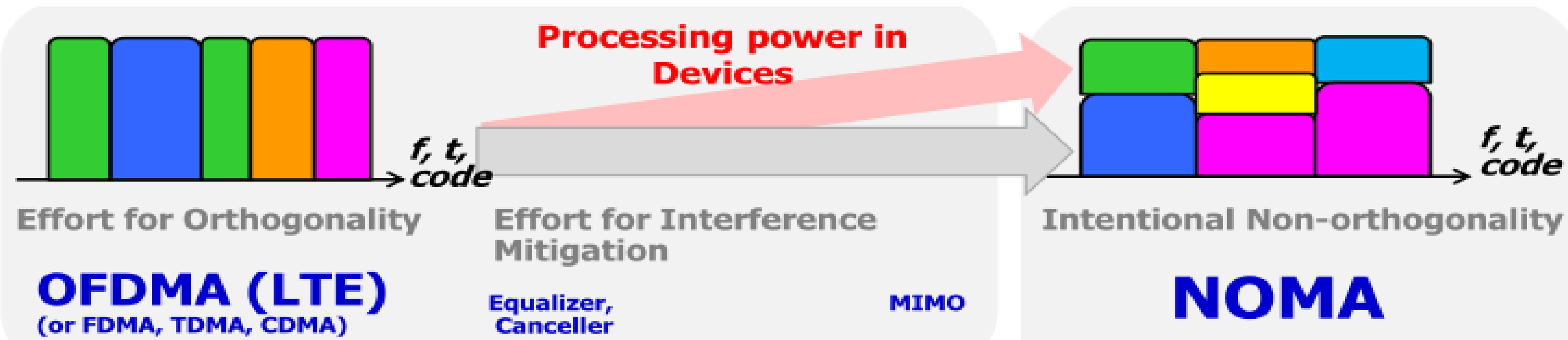


Self-interference cancellation Procedure[1]

[1]*Source: 5G White paper Future Mobile Communication Forum*

5G Key technological components - Radio

- **Alternative Multiple Access**
  - Non-Orthogonal Multiple Access (NOMA)



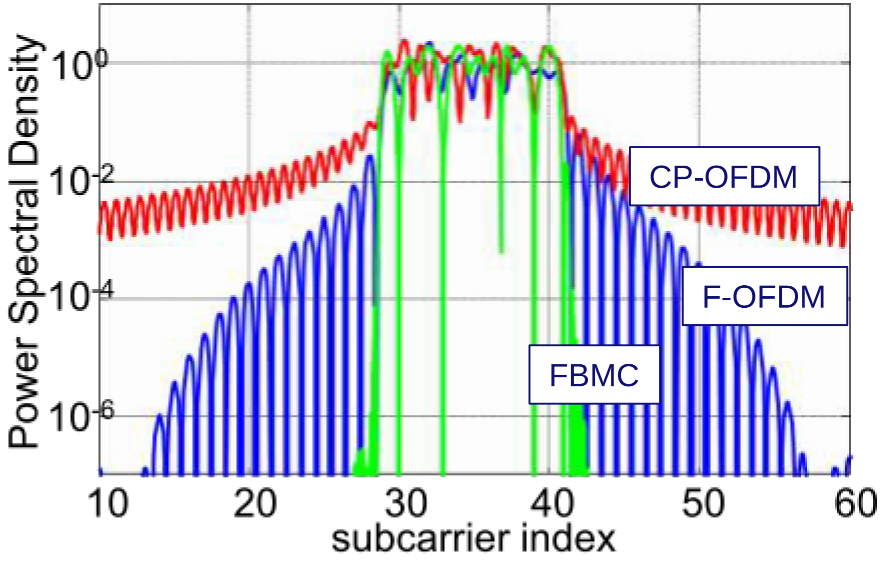
  - Increase spectral efficiency
  - Combined with SIC at the receiver
  - Increase of complexity

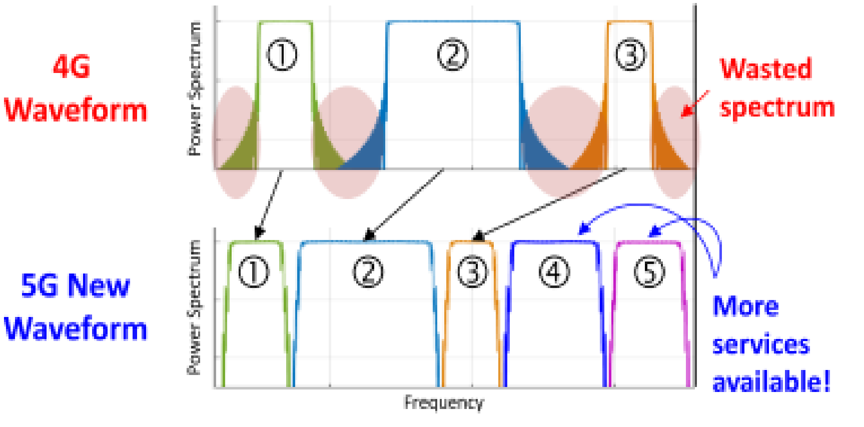
Source: T. Nakemura, Towards 5G Deployment in 2020 and Beyond

5G Key technological components -Radio

- **Alternative waveforms**
  - Flexible waveforms to support both broadband and IoT
  - New waveforms to significantly reduce the out-of-band leakage
    - Filter bank multicarrier and filtered OFDM as alternative to CP-OFDM

Waveform





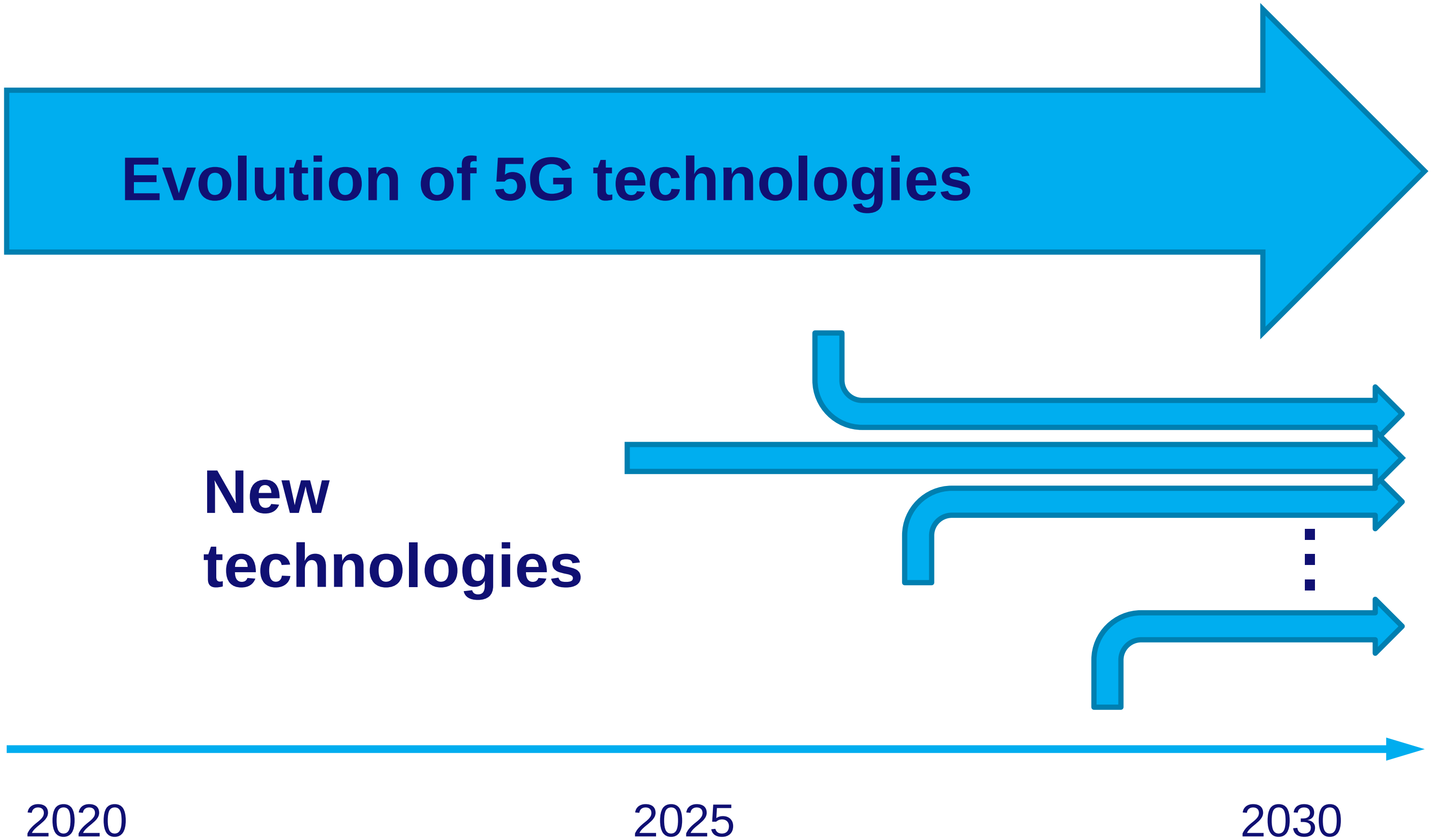
Source: T. Nakemura, Towards 5G Deployment in 2020 and Beyond

Advanced 5G and Beyond
TECHNOLOGIES

5G + Requirements

- Perception of “Infinite” capacity
  - Ultra-high data rates
  - Massive scalability to millions of devices
- Coverage
  - Ubiquitous consistent user experience in time and location
- Convenience
  - Extreme low latency (interactive services, tactile internet, remote surgery)
  - Long battery life/ ultra-low energy consumption

Wireless Research for Beyond 5G

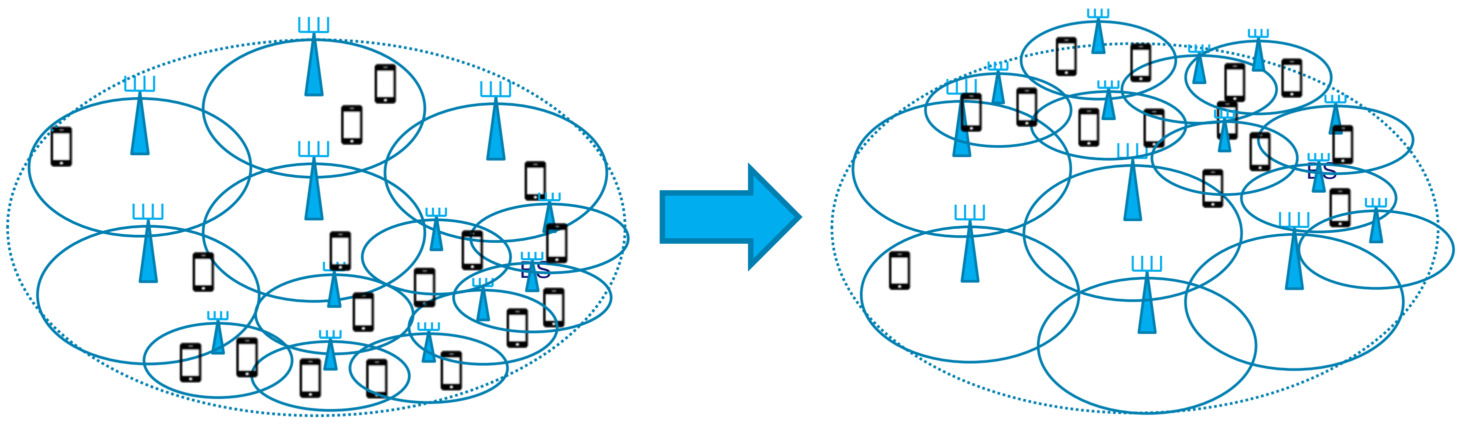


Wireless Research for 5G+ (1)

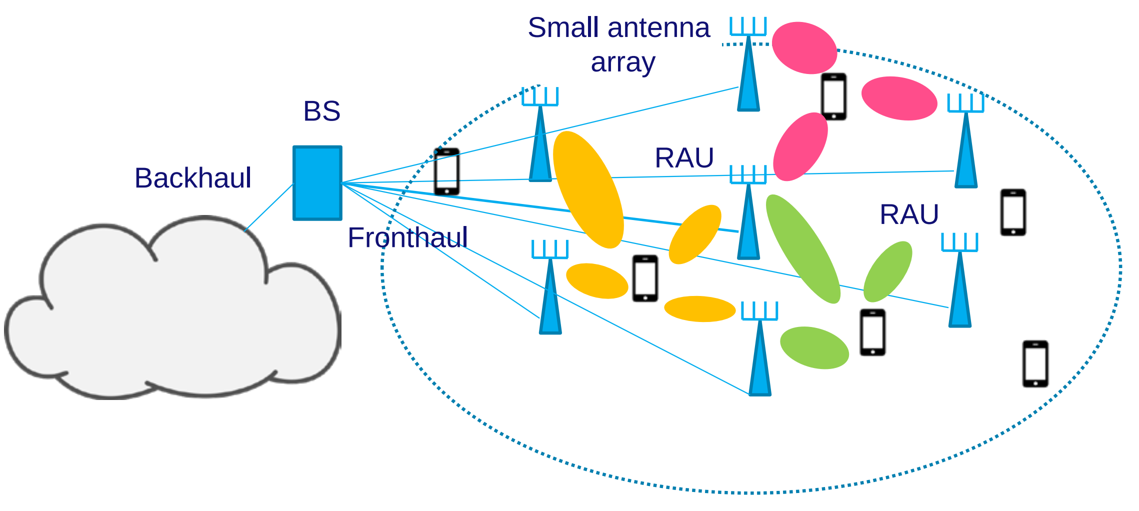
- **Evolutionary techniques**
  - **Increase spectral and energy efficiency**
  - **Flexible allocation of capacity**
  - **Advanced radio coordination techniques, e.g., distributed massive MIMO**

5G+: Flexible allocation of capacity

- **Radio network dynamic reconfiguration**
- **Adaptive density of active antennas**
- **Different network overlays for different traffic classes**
- **Moving cells**
- **Wireless back/front haul**



5G+: Distributed Massive MIMO

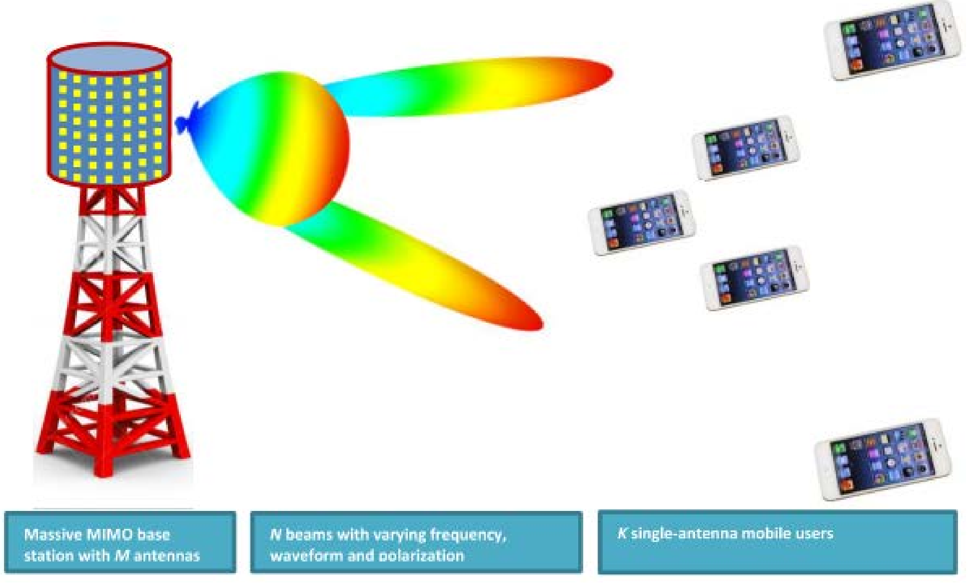


Wireless Research for 5G+ (2)

- **Use of higher spectral bands**
  - **30GHz – 300GHz**
  - **Communication and sensing**
    - Cellular radar
  - **Accurate positioning/localization**
  - **Optical wireless communication**
    - Visible light communication (VLC)
    - IR communication
  - **THz systems for sensing and communications**

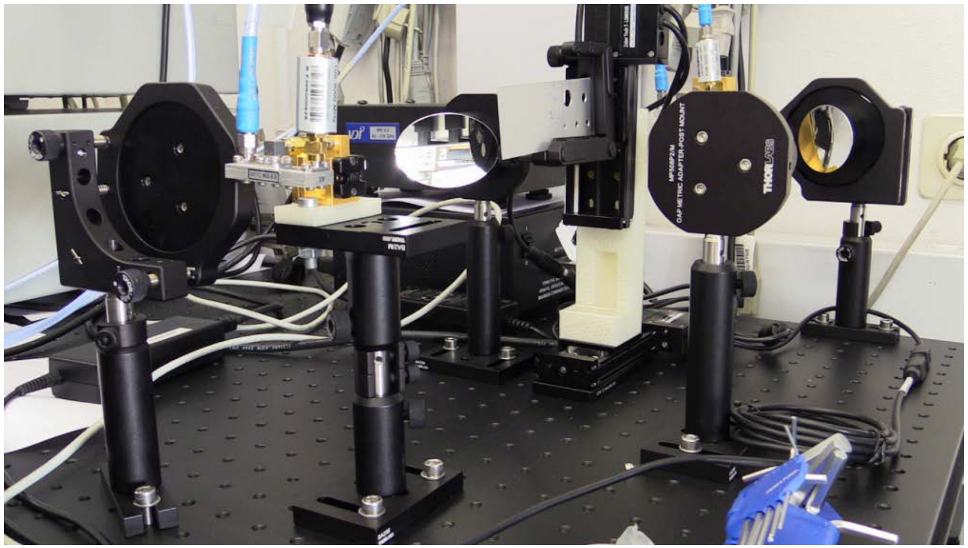
5G+ Antenna technology

- **H2020 SILIKA Project (Prof. B. Smolders)**
  - **mmwave multi-antenna systems for energy-efficient and low cost base stations for 5G wireless infrastructure**



Technologies for very high carrier frequencies

THz Systems



THz lab set up - Dr. M. Matters

presenteerde om het delen van transportmiddelen te faciliteren. Dat is wenselijk, omdat de gemiddelde bezettingsgraad van voertuigen de afgelopen twintig jaar met zo'n 10 % is afgenomen. Sharif Azadeh ontwierp een systeem waarin passagiers kunnen aangeven welke reis (waarheen en wanneer) zij willen maken en of zij

keuze verandert onder invloed van gezondheidsbeleid.'
De hoeveelheid data die je in modellen kunt stoppen lijkt schier oneindig, maar worden ze daar ook nauwkeuriger van? Volgens Chorus zijn eenvoudige modellen op hoofdlijnen vaak al 90 % nauwkeurig. Maar dat maakt die laatste 10 % niet minder interessant. TW
www.heart2016.org/

wege de logistiek en de windbelasting de grootste uitdaging. Het 55 m lange en 560.000 kg wegende val werd met twee drijvende bokken naar een locatie elders gebracht om daar gerenoveerd te worden. Ondertussen worden alle evenwichts- en bewegingskabels van het val vervangen. Eind dit jaar moeten alle werkzaamheden klaar zijn. TW
https://goo.gl/Ys3QGc

Boeken lezen met terahertzstraling

/// *Eerste prototype*
/// *Negen pagina's diep*

INDRA WAARDENBUG

ICT Onderzoekers van MIT zijn erin geslaagd om met een zelf ontwikkeld systeem door de eerste negen pagina's van een stapel papier te kijken. Het systeem maakt hiervoor gebruik van terahertzstraling, elektromagnetische straling met een golflengte tussen die van infrarood- en microgolfstraling. Met hun onderzoek, waarvan zij de eerste resultaten onlangs publiceerden in het blad Nature Communications, bouwen de wetenschappers voort op een technologie om door enveloppen heen te kijken zonder deze te openen.
Het prototype bestaat uit een terahertzcamera die ultrakorte pulsen uitzendt. Een ingebouwde sensor in de camera detecteert de reflectie van deze pulsen. Deze reflectie ontstaat doordat er zich minuscule luchtzakjes van 20 µm diep tussen de pagina's bevinden. Het verschil in refractie tussen lucht en papier zorgt voor de terugkaatsing van de terahertzstraling. Met behulp van een door de onderzoekers ontwikkeld algoritme blijkt de afstand tussen de verschillende bladzijden te bepalen. Hierbij kijkt het systeem naar de tijd tussen het uitzenden en het ontvangen van de straling. Daarnaast is het algoritme in staat om letters te identificeren, zelfs als de beelden vervormd zijn, of er delen van letters ontbreken.
Met het prototype konden de onderzoekers succesvol door de eerste twintig pagina's komen. Doordat het signaal deels wordt geabsorbeerd en deels heen en weer kaatst tussen de verschillende pagina's, is het signaal echter na negen pagina's zo zwak dat achtergrondruis het overstemt.
De onderzoekers willen nu de nauwkeurigheid van de detectoren verbeteren en de stralingsbron versterken. TW
https://goo.gl/rWDg7H

BARMAK HESHMAT

THz Imaging

Terahertz band: Next frontier for wireless communications

Wireless Research for 5G+ (3)

- **Network intelligence/cognitive networks**
  - To deal with extreme large number of devices
  - To deal with high level of system complexity and uncertainties
  - Machine learning techniques
  - Self-organizing systems/autonomous, and self evolving systems

Network intelligence

- **Cognitive networks (Prof. A. Liotta)**
  - Automatic anomaly detection based on machine learning (running directly inside the sensor).
  - IoT playground with accurate monitoring, logging and analytics

Wireless Research for 5G+ (4)

- **Device miniaturization**
- **Extreme low power/ battery-less**
  - Cell powered devices and systems
- **Wearable electronics, flexible electronics, implantable electronics**

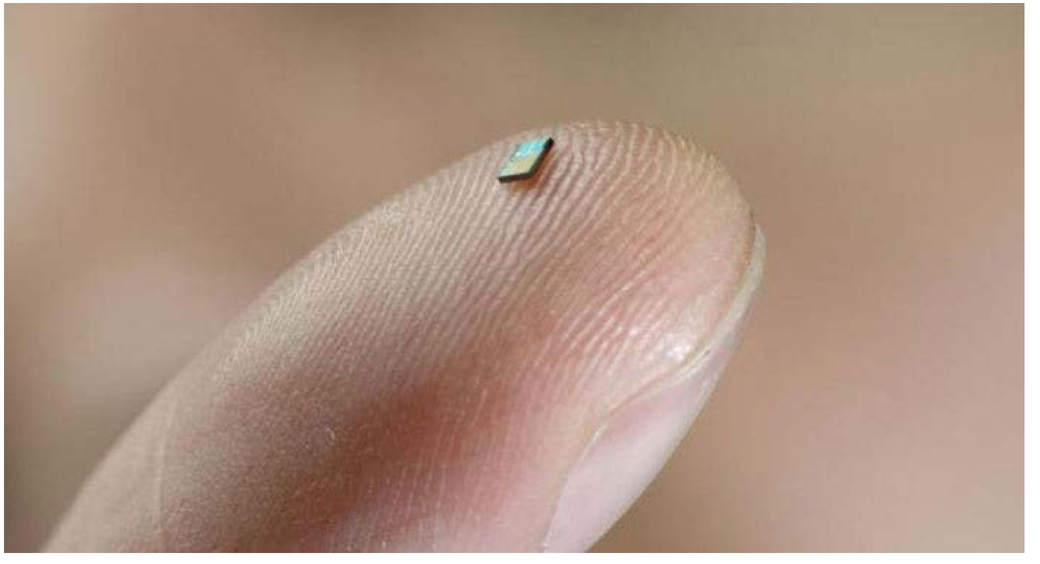
  In-body, on-body, from-body communication
- **Intelligence/sensing/communication embedded in the body and in the environment**

Extremely low-power devices

- **Pushing the limits of miniaturization and ultra-low power**

  CWTe –Premiss (Dr. Hao Gao)

  60GHz energy harvesting temperature sensor

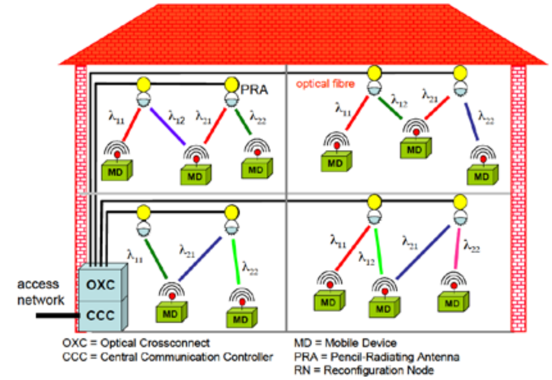


Wireless Research for 5G+ (5)

- **Close interworking wireless/optical communication**
  - Optical will be needed because of capacity and latency
  - Dynamic transport/routing for provision of capacity on demand
  - Optical-wireless communication

Optical technologies

- **Browse project – T. Koonen et al**
  - Multiple dynamically-steered free-space optical beams (downstrean)
  - flexible mmwave radio communication techniques (upstream)



CONCLUSION

Final Remarks

- 5G is a big step to advance wireless systems
  - Extreme variation of requirements
  - Multiple challenges
  - First phase 2020-2025 lower frequencies
  - Second phase 2025-2030 mmwave
- Research beyond 5G
  - Evolution of 5G techniques
  - New technologies
- CWTe at TU/e working on 5G and beyond key research areas using interdisciplinary approach

Thank you!

Feeling the (Pain of) Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, …

Richard Li, PhD

Chief Architect, Future Networks
Huawei USA
Renwei.Li@huawei.com

HUAWEI TECHNOLOGIES CO., LTD.

Expectation Always Grows with Success!

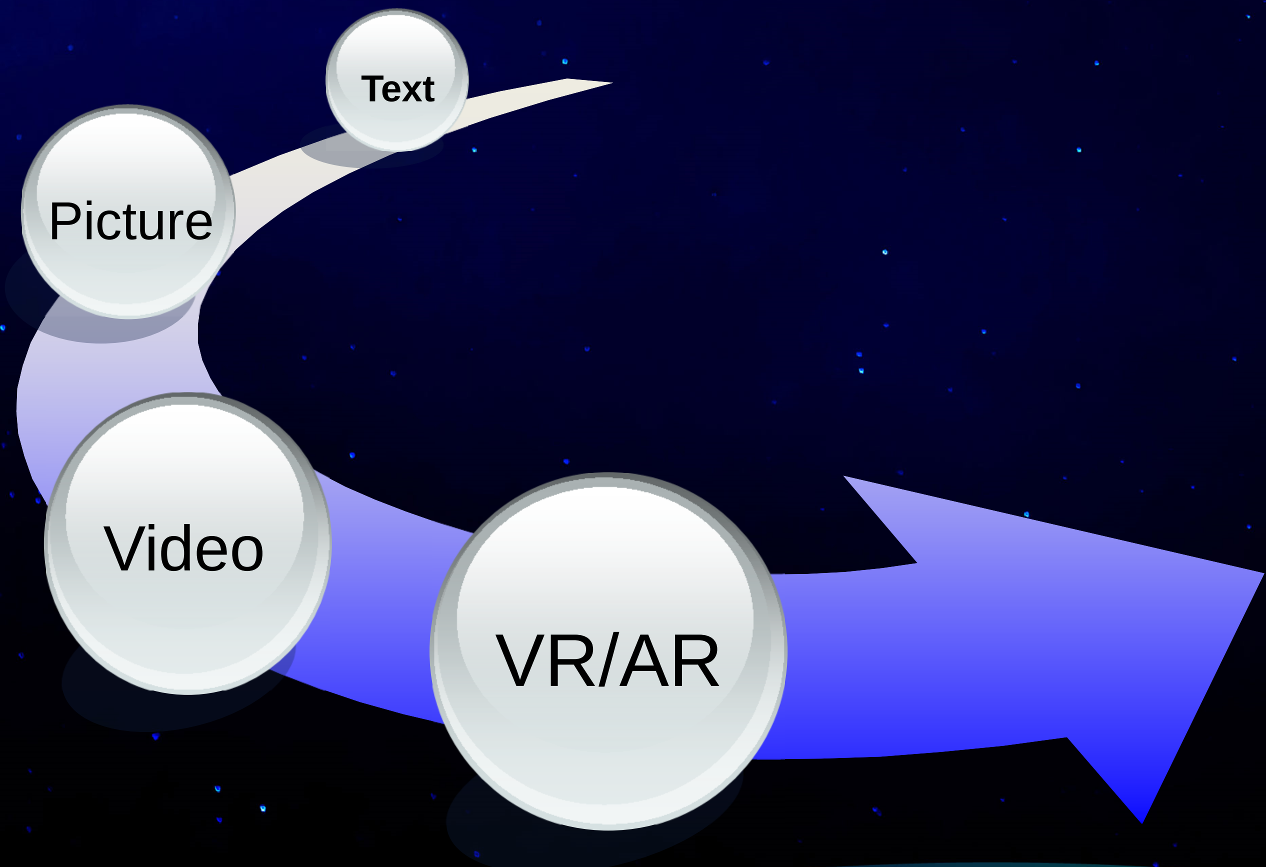
Expectation for runners:

- **When you run 100 meters in 10 seconds, you are expected to run it in 9.5 seconds**
- **When you reach 9.5 seconds, you are expected to run it in 9 seconds**
- **You will always be expected for something newer and harder!**

Expectation for the Internet

- **TCP/IP was initially expected to send/receive “lettergrams”**
- **When the Internet can successfully support “textual” applications, it is expected to support “image applications”**
- **When the internet can support “voice applications”, it is expected to support “video” applications**
- **When the internet can support video applications, it is expected to support “immersive experience” applications. But can it really support it?**

Evolution of Internet Applications



AR/VR: New Way to Live, to Play, to Work, to Share, to Design, to Experience, to Go beyond the Screen

Source: Modification of https://www.youtube.com/watch?v=aThCr0PsyuA

Can the Internet Support any New Applications?

New Requirements

- High Throughput (1-10Gbps)
- Low Latency (1ms)

Obstacles

Physics

❖ Light speed: 300km/ms

Protocols

❖ 40-year old design

Real Transport: 100km/ms

Economics

❖ CapEx
❖ OpEx

Emerging Technologies

mmW, 5G, IoT, V2X, ION, SDN, NFV, MEC

Panelists

- **Tommy Svensson:** Challenges and Opportunities with mm-wave Communications in 5G
- **Valerio Frascolla:** Mobile Edge Computing, a key building block for 5G networks
- **Eugen Borcoci***:* Centralized SDN control in distributed IoT environment - is it possibly an efficient cooperation ?

Thank you

www.huawei.com

Panel on Communications on ICN & SPACOMM

Topic: Feeling the (Pain of) Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

SDN, NFV, MEC.. in IoT Environment?

Eugen Borcoci
University POLITEHNICA Bucharest
Electronics, Telecommunications and Information Technology Faculty (ETTI)
Eugen.Borcoci@elcom.pub.ro

NexComm Conference, 23-27 April, Venice

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

Facts:

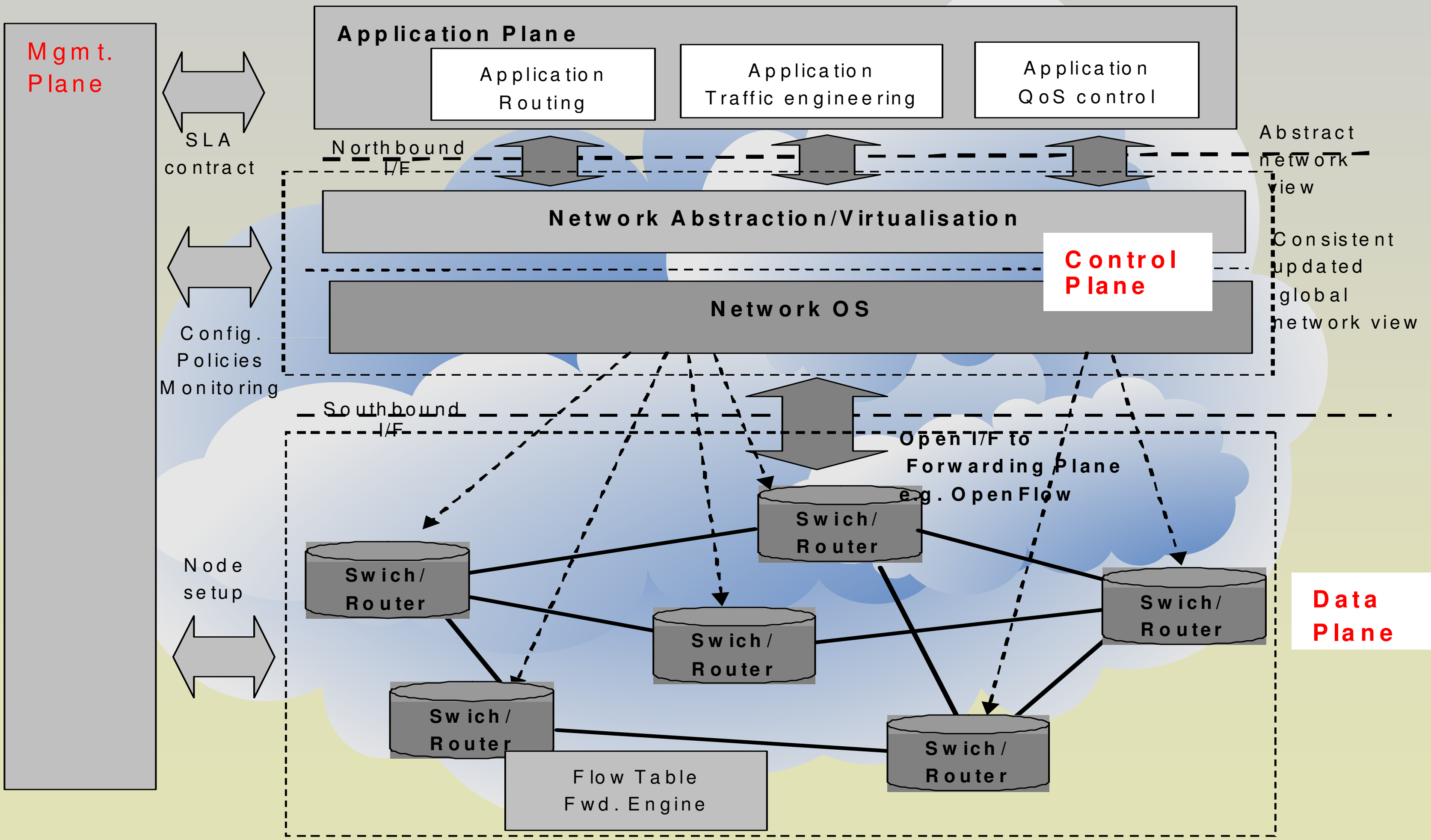
- **Internet and Telecom convergence → Integrated networks: Future Internet**
- **Novel services, applications and communication paradigms**
  - **Internet of Things (IoT) and Smart cities, M2M and Vehicular communications, Content/media oriented communications, Social networks,**
  - **Internet of Everything (IoE), etc.**
- **Novel, emergent technologies** are changing networks and services architectures :
  - ***Supporting technologies***
    - ***Cloud Computing***
    - ***Fog/Edge Computing /Mobile Edge Computing /Cloudlets***
    - ***Software Defined Networks (SDN)***
    - ***Network Function Virtualization (NFV)***
    - ***Advances in wireless technologies: 4G-LTE, LTE-A, WiFi, 5G***

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Software Defined Networking (SDN)**
  - **SDN – applicable in Clouds, WANs, IoT, vehicular, 5G**
- **SDN concepts and advantages:**
  - **Control Plane (CPl) and Data Plane (DPl) separation**
  - **centralized logical control and view** of the network
    - underlying network infrastructure is abstracted to applications
    - common APIs (northbound I/F)
  - Open I/Fs Southbound I/F CPl (controllers - DPl elements)
    - E.g. OpenFlow
  - **Network programmability**: by external applications including network management and control
  - **Independency of operators** w.r.t. network equipment vendors
  - Increased network reliability and security

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- ## SDN –architectural planes separation

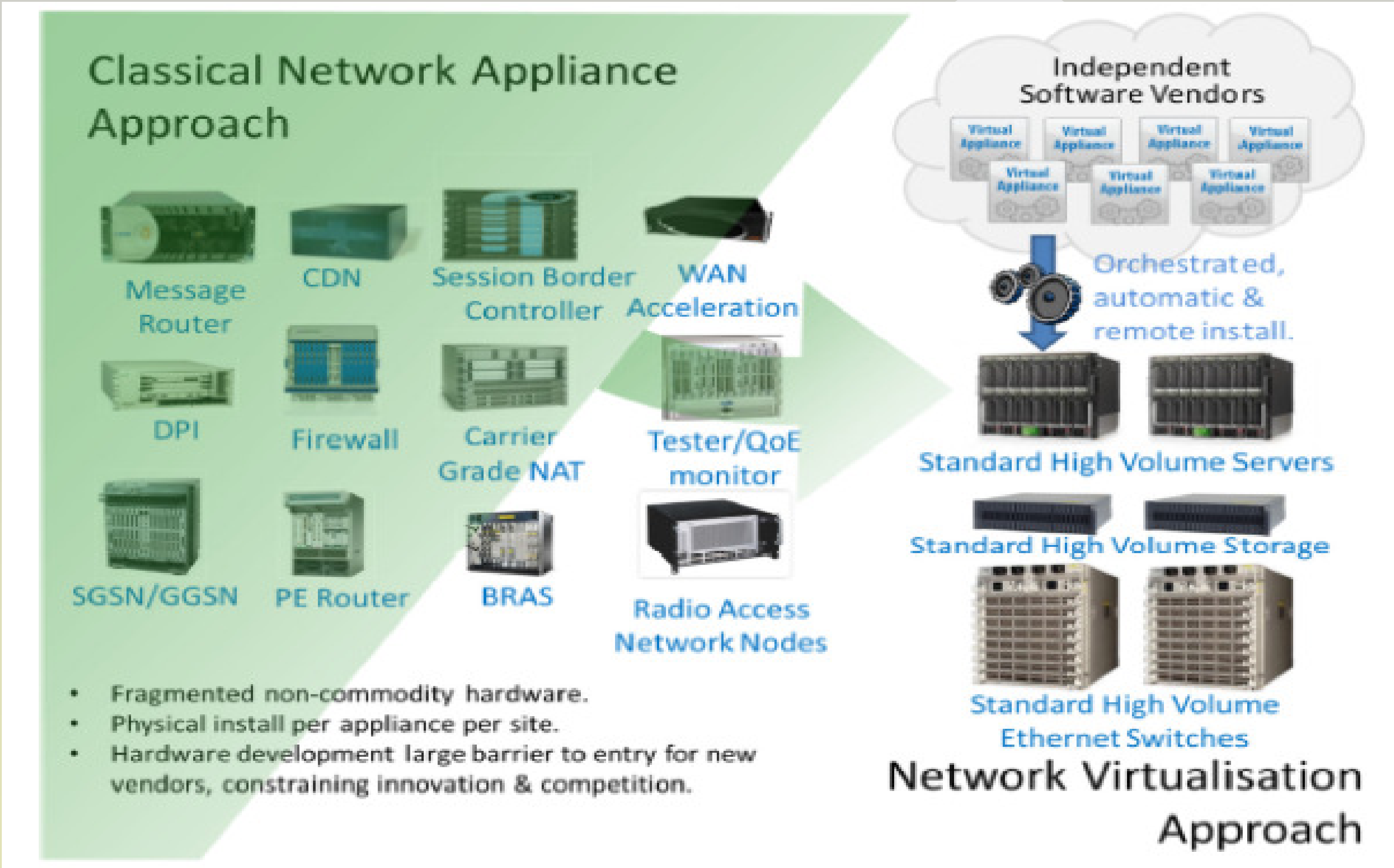


Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Network Function Virtualization (NFV)**
  - Using COTS computing HW to provide **Virtualized Network Functions (VNFs)**
    - Sharing of HW and reducing the number of different HW arch.
  - **High flexibility in assigning VNFs to HW**
    - better scalability (hope)
    - decouples functionality from location
    - enables time of day reuse
    - **Virtualization-** → flexibility and resource sharing
  - **Rapid service innovation** through SW -based service deployment
  - Higher **operational efficiencies**
  - **Reduced power consumption**
    - (VNF migration, instantiation, …)
  - **Standardized and open I/Fs**: between VNFs infrastructure and mgmt. entities

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

NFV vision (source : ETSI)



Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

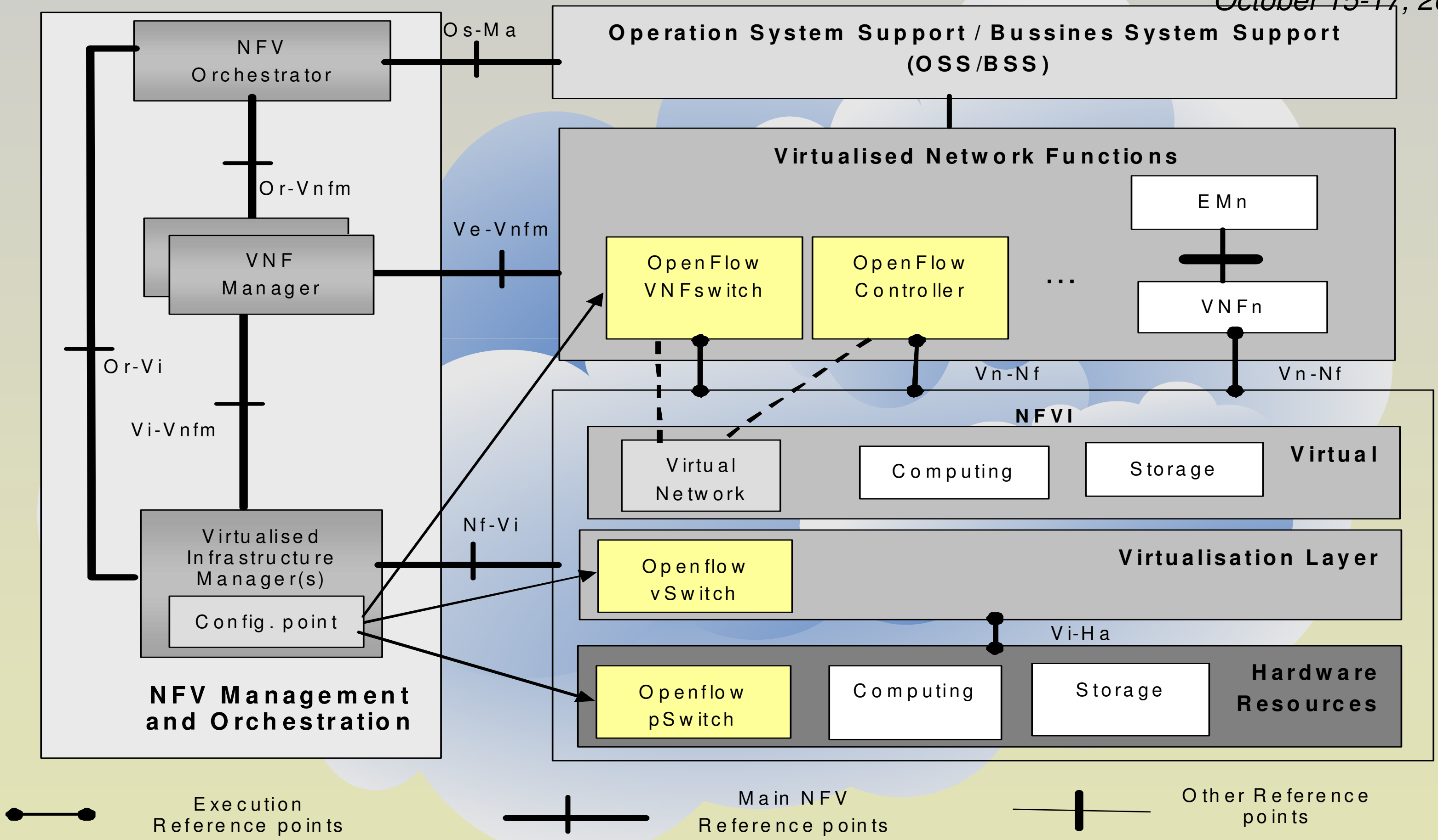
- **SDN and NFV –complementary (orthogonal?)**
  - SDN - **horizontal** separation in planes
  - NFV - **vertical** separation : HW/SW (applicable in both CPl and DPl)
  - They can be developed together
    - NFV provides functionalities
    - SDN provides "Tools"

- Cooperation
  - ETSI
  - ONF
  - IETF
  - ….

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

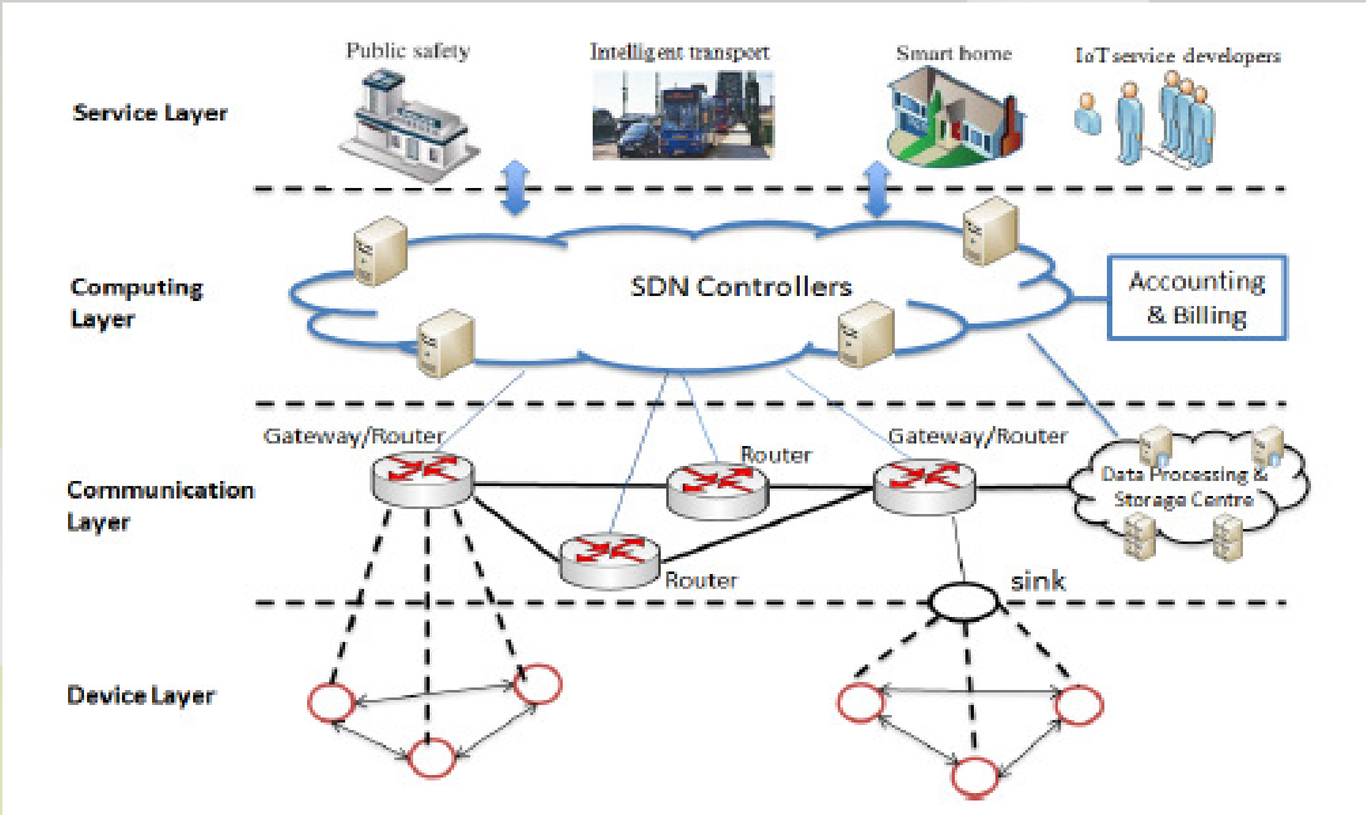
- **SDN and NFV –are complementary- example**

Source: "SDN and OpenFlow World Congress", Frankfurt, October 15-17, 2013



Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

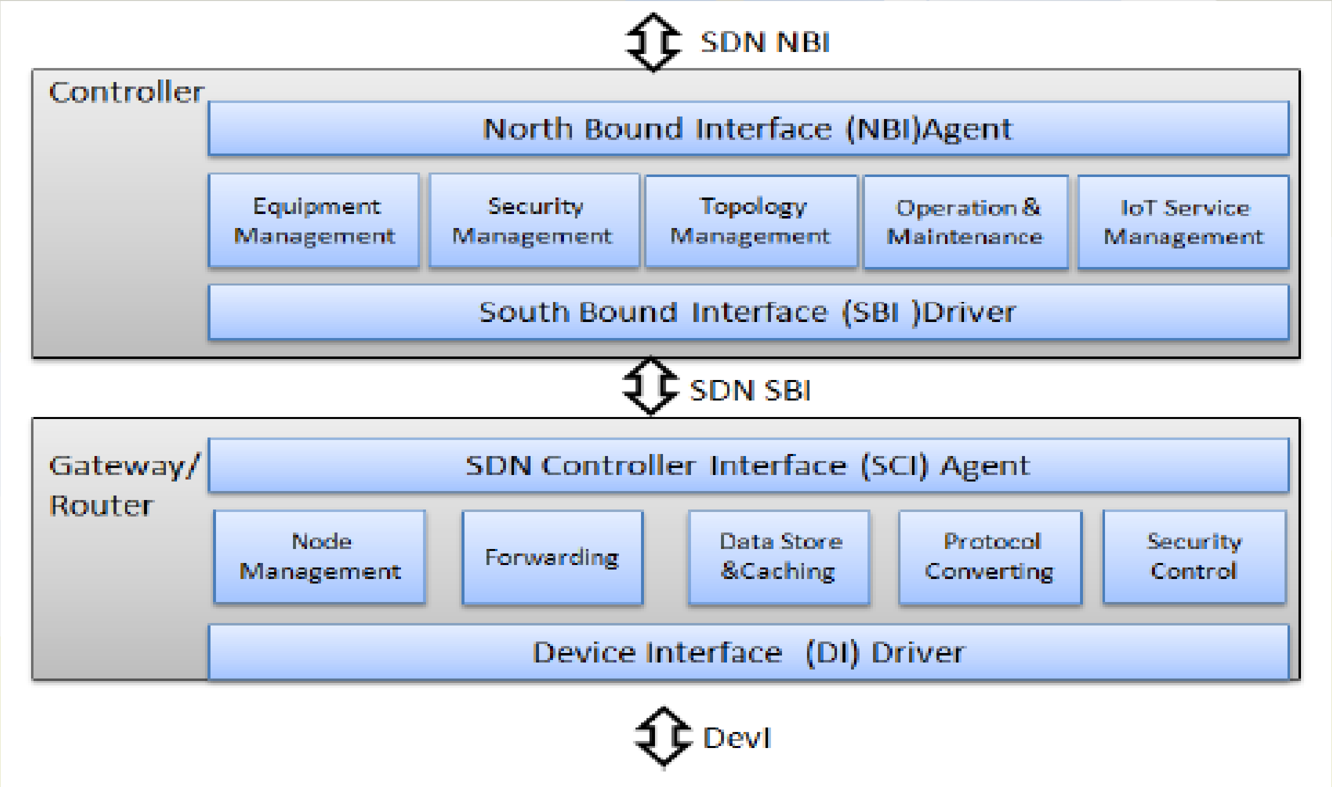
- **SDN control of IoT- example 1**



Source: Y.Li, et.al, "A SDN-based Architecture for Horizontal Internet of Things Services", ICC Conference, 2016

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

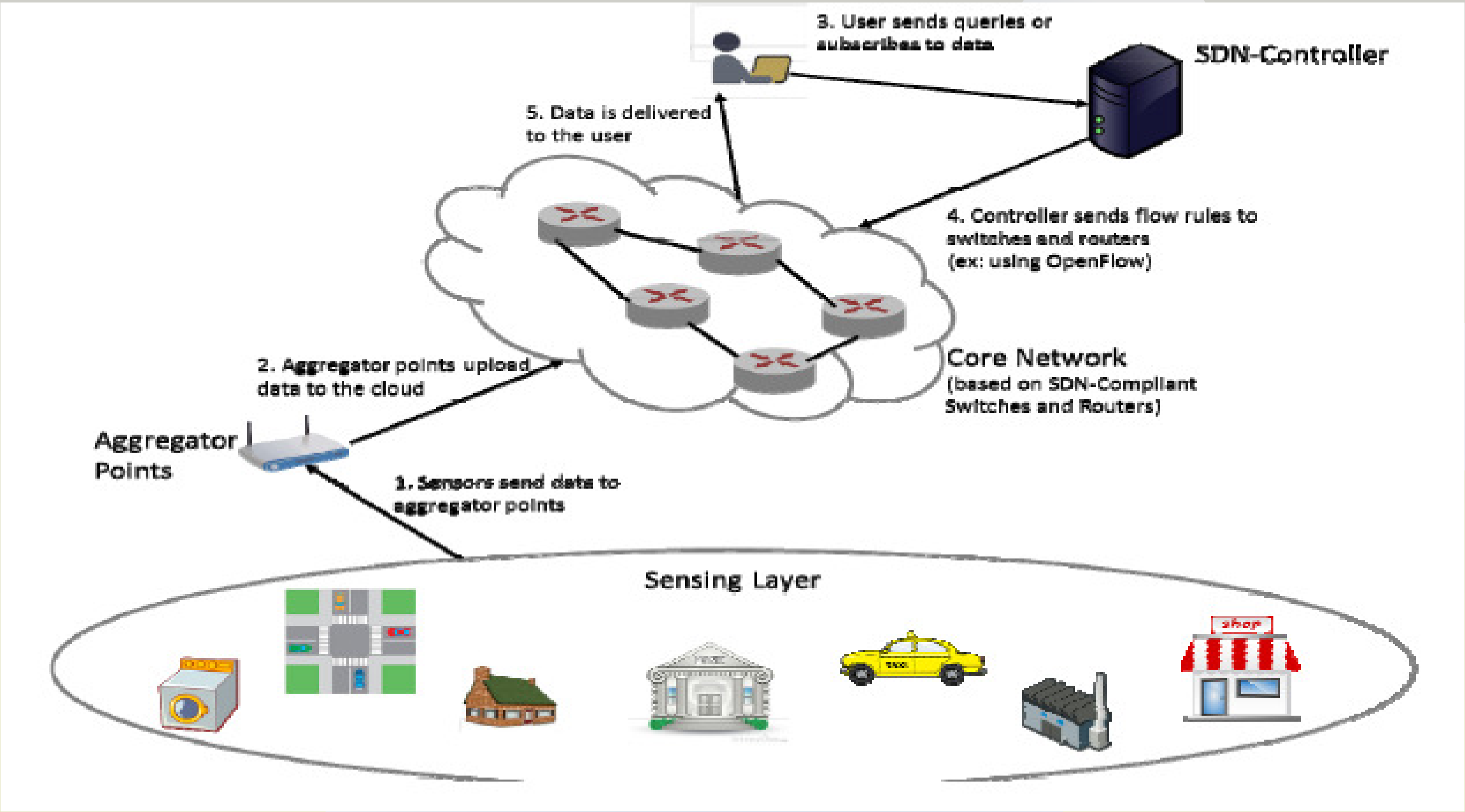
- **SDN control of IoT- example 1 (cont'd)**
- **Functional modules of the controller and gateways**



Source:Y.Li, et.al, "A SDN-based Architecture for Horizontal Internet of Things Services", ICC Conference, 2016

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

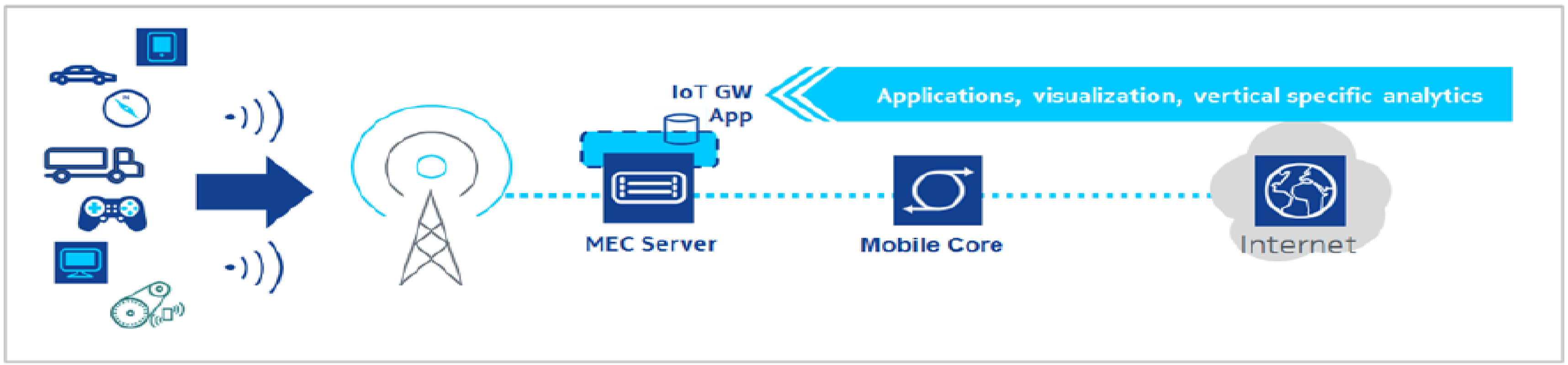
- **SDN control of IoT- example 2 (ICN-style architecture)**



Source: Amr El-Mougy, et.al., "Software-Defined Wireless Network Architectures for the Internet-of-Things", LCN 2015, Florida, USA

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **MEC Use Cases example- IoT**
- Internet of Things (IoT)
  - IoT devices: Often limited (processor, memory capacity)→ need for messages aggregation , security , low latency ..
  - r.t. capability → grouping of sensors and devices is needed for efficient service.
  - Possible Solutions:
    - IoT manipulated close to the devices (e.g., MEC server)
    - This also provides an analytics processing capability and a low latency response time.



Source: Yun Chao Hu et.al., "Mobile Edge Computing A key technology towards 5G" ETSI White Paper No. 11 September 2015, ISBN No. 979-10-92620-08-5

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Conclusions**
- Significant effort exist towards convergence/cooperation
  - **Technologies**
    - SDN- NFV
    - SDN- NFV- 4G-5G
    - CC- EC/Fog- 5G
    - EC/Fog-MEC- Cloudlets
    - CC-SDN-NFV- IoV
    - CC-SDN-NFV- IoT
    - **Issues: eliminate parallelism and overlapping between standardization efforts……**
  - **Different functional and business aspects**
    - Management and control
    - Slicing and virtualization
    - Security, privacy
    - Scalability
      - Interoperability
    - Seamless deployment characteristics
    - Support for apps and services
  - **New business models**
  - ……

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- Thank you !

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **References**

1. ETSI- Network Functions Virtualization – Introductory White Paper, https://portal.etsi.org/nfv/nfv_white_paper.pdf
2. ETSI GS NFV 002 v1.2.1 2014-12, NFV Architectural Framework
3. ONF, “OpenFlow-Enabled SDN and Network FunctionsVirtualization,” https://www.opennetworking.org/images/stories/downloads/sdn-resources/solutionbriefs/sb-sdn-nvf-solution.pdf;
4. https://www.sdxcentral.com/sdn-nfv-use-cases/
5. M.Mendonca, et. al., A Survey of Software-Defined Networking: Past, Present,and Future of Programmable Networks, 2014, http://hal.inria.fr/hal-00825087
6. Y.Li, et.al, "A SDN-based Architecture for Horizontal Internet of Things Services", ICC Conference, 2016
7. Amr El-Mougy, et.al., “Software-Defined Wireless Network Architectures for the Internet-of-Things”, LCN 2015, Florida, USA
8. Yun Chao Hu et.al., "Mobile Edge Computing A key technology towards 5G" ETSI White Paper No. 11, September 2015, ISBN No. 979-10-92620-08-5

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **Backup slides**

Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, ...

- **List of Acronyms**

BS	Base Station
BSS	Business Support System
CC	Cloud Computing
CCN	Content Centric Networking
COTS	Commercial-off-the-Shelf
EC	Edge Computing
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FC	Fog Computing
FCN	Fog Computing Node
IoT	Internet of Things
LTE	Long Term Evolution
MEC	Mobile Edge Computing
M&O	Management and Orchestration
MME	Mobility Management Entity
NF	Network Function
NFV	Network Functions Virtualization
NFVI	Network Functions Virtualization Infrastructure
NO	Network Operator
NP	Network Provider
NS	Network Service
OSS	Operations Support System
SDN	Software Defined Network
SLA	Service Level Agreement
SP	Service Provider

Intro to Panel on "Feeling the Pain of Convergence: mmWave, 5G, SDN, NFV, IoT, ION, MEC, …"

Tommy Svensson

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Department of Signals and Systems, Communication Systems Group

Chalmers University of Technology, Sweden

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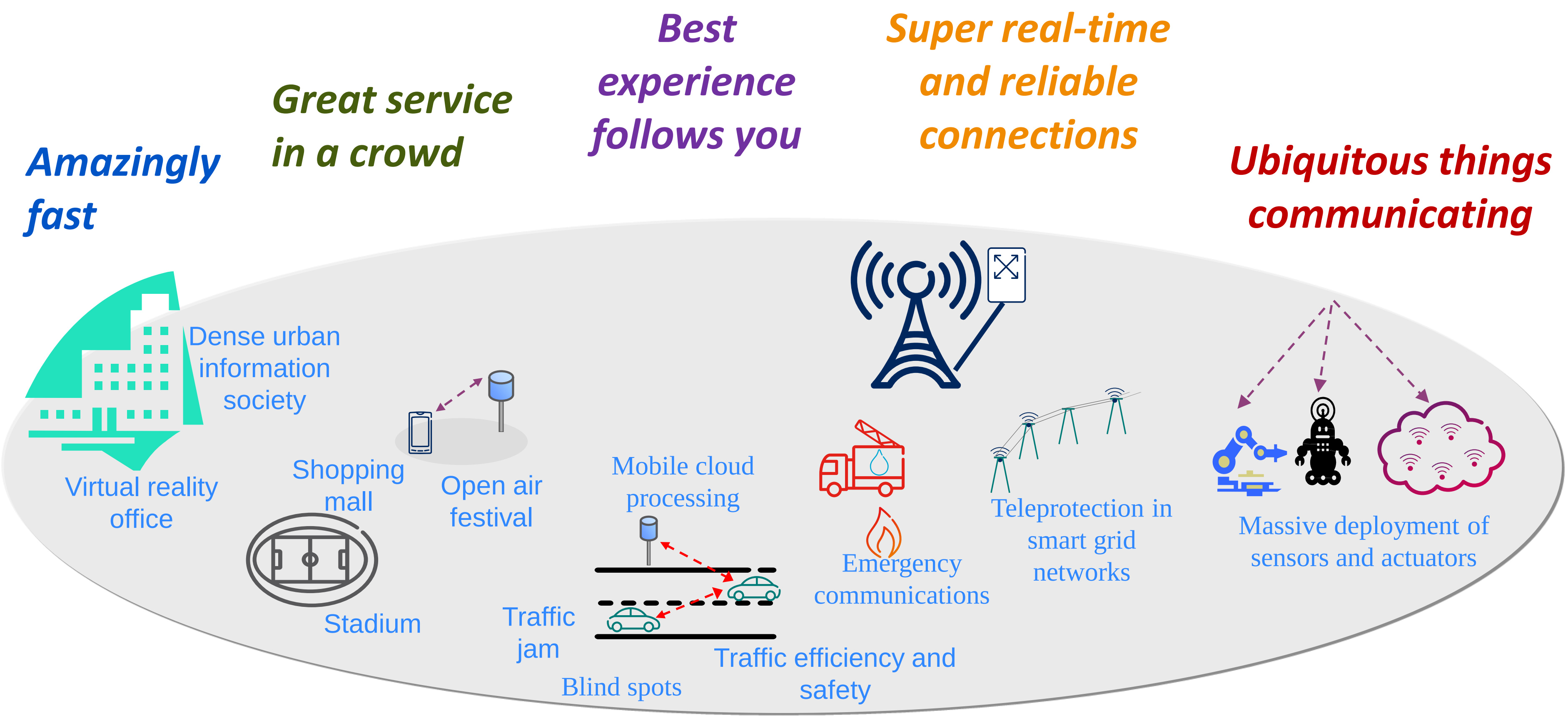
www.chalmers.se/en/staff/Pages/tommy-svensson.aspx

CHALMERS

METIS Scenarios and Test Cases



Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

Additional use cases has been proposed by NGMN Alliance, 'NGMN White Paper,' Feb. 2015 (available online https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf)

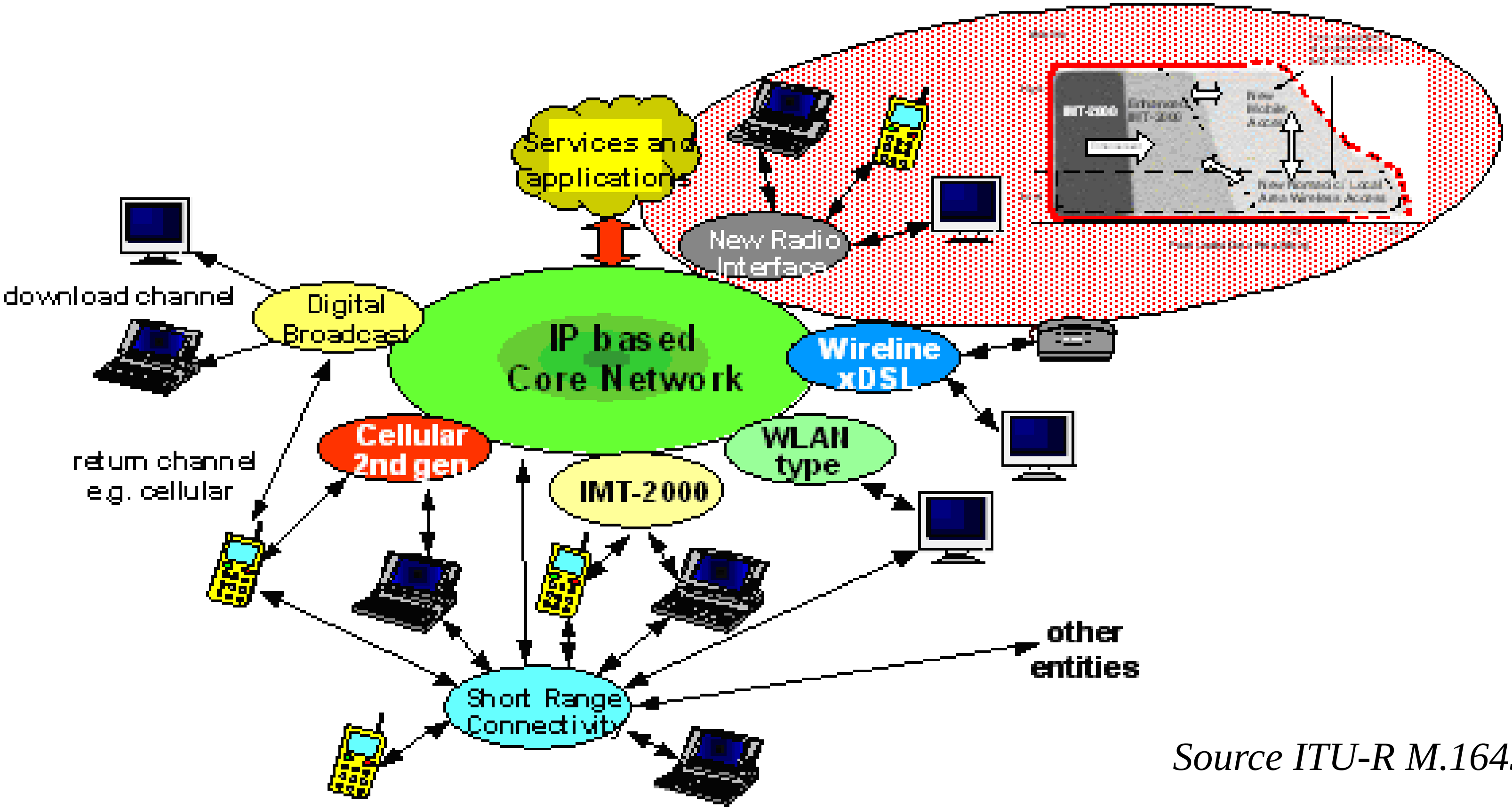
METIS Overall Technical Goal

A system concept that, relative to today, supports:

- 1000 times higher mobile data volume per area,
- 10 times to 100 times higher number of connected devices,
- 10 times to 100 times higher typical user data rate,
- 10 times longer battery life for low power Massive Machine Communication (MMC) devices,
- 5 times reduced End-to-End (E2E) latency.

Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

Recap: ITU-R Vision for Systems Beyond 3G



Source ITU-R M.1645

Integrate existing and evolving access systems on a *packet-based* platform to enable cooperation and interworking.

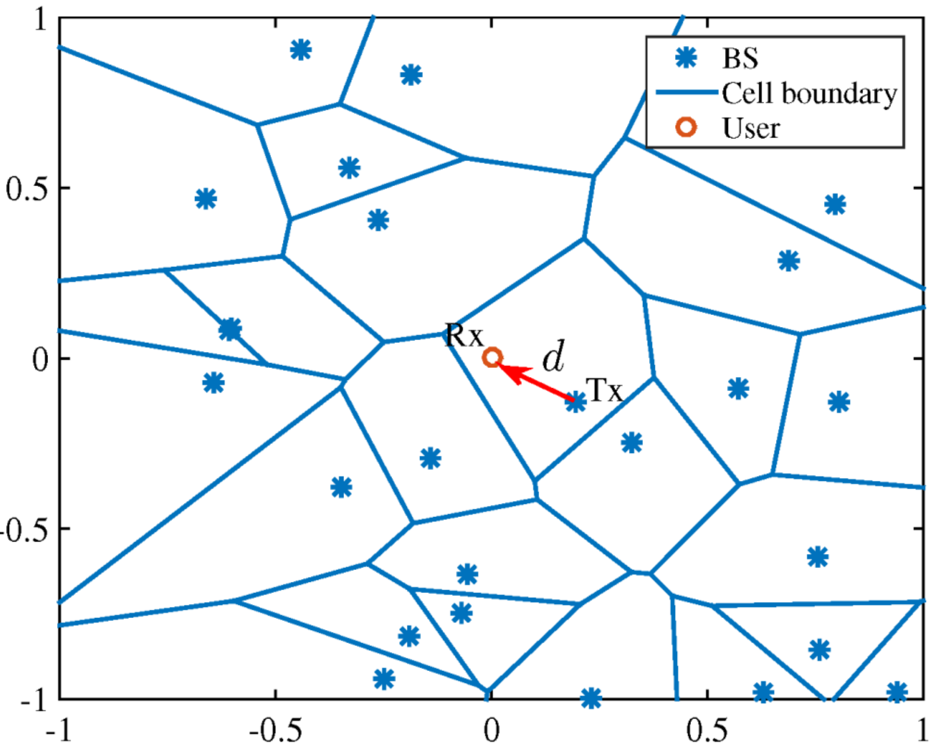
“Optimally connected anywhere, anytime"

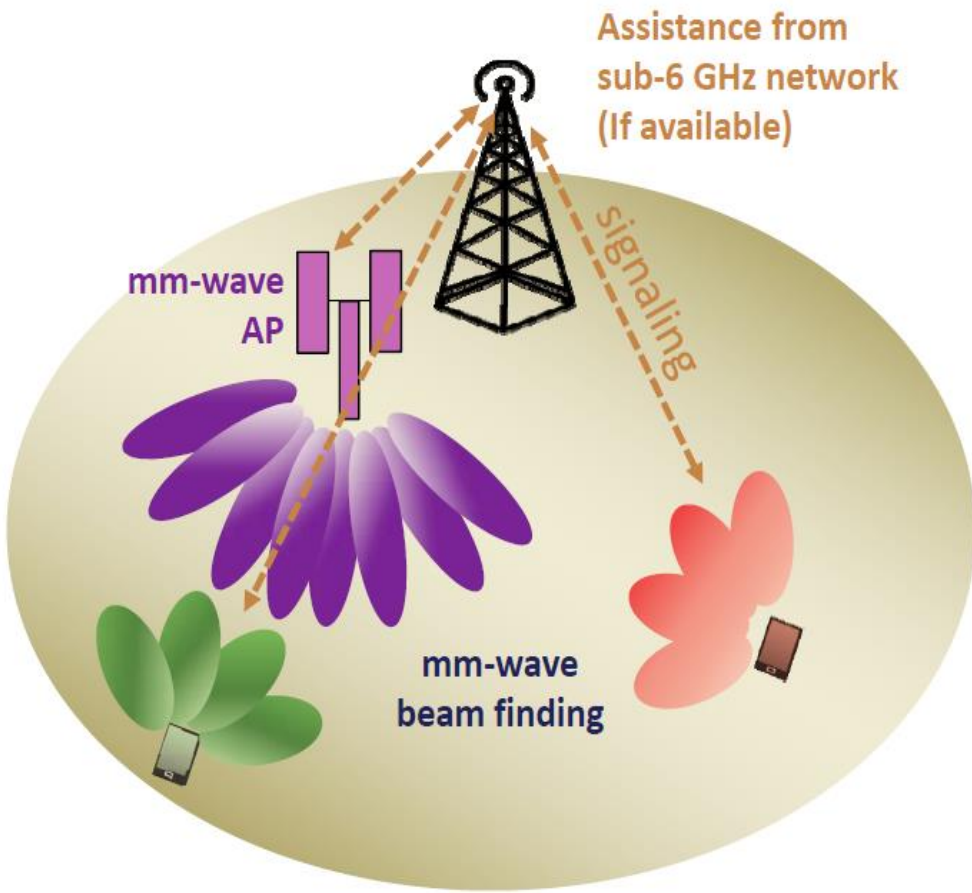
We have done it once already – On the terminal side!

Flexibility versus Efficiency

Picture source: http://onpr.com/choosing-the-right-smartphone-its-easy-to-decide/

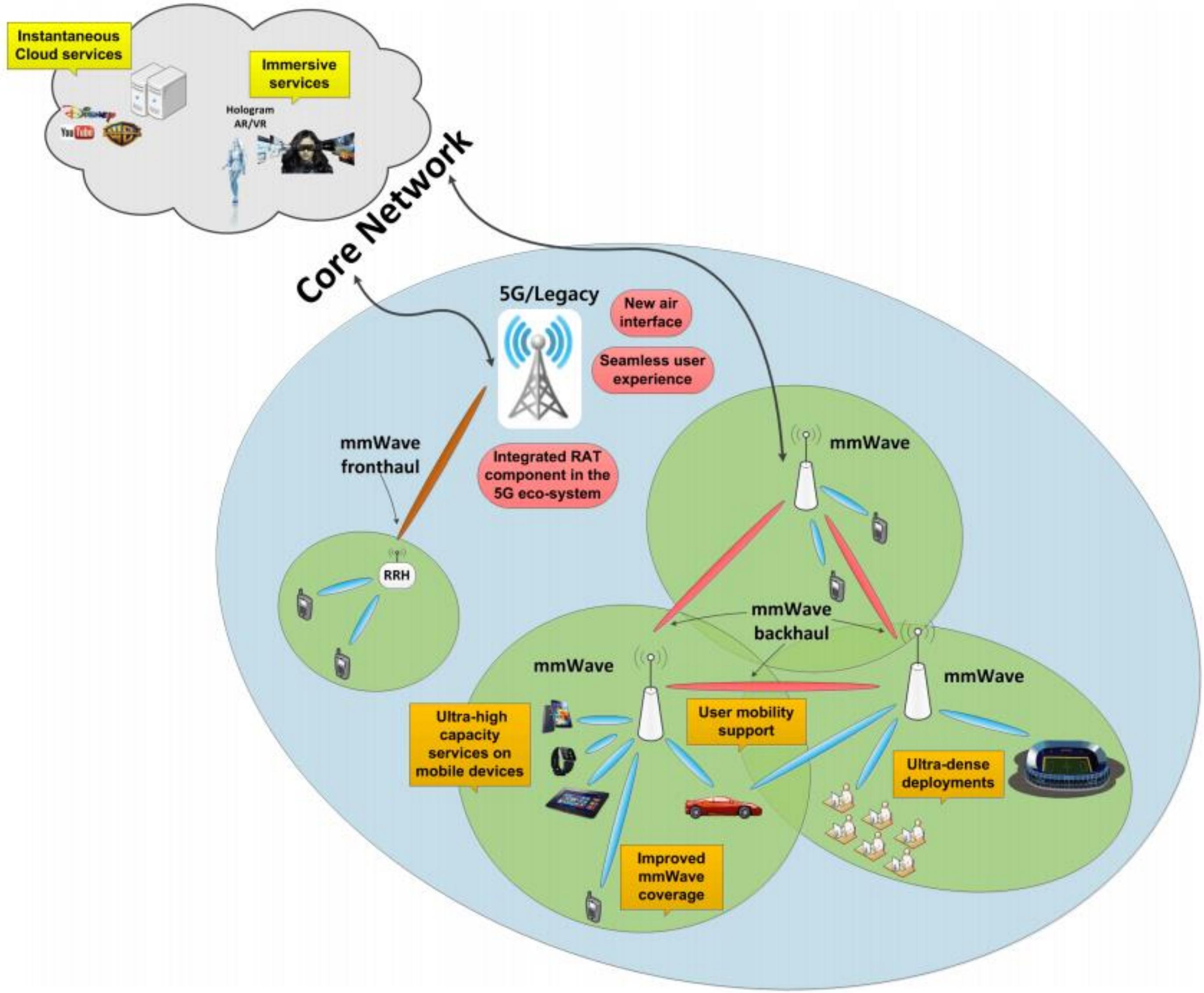
From hexagonal cells to unstructured beam spaces



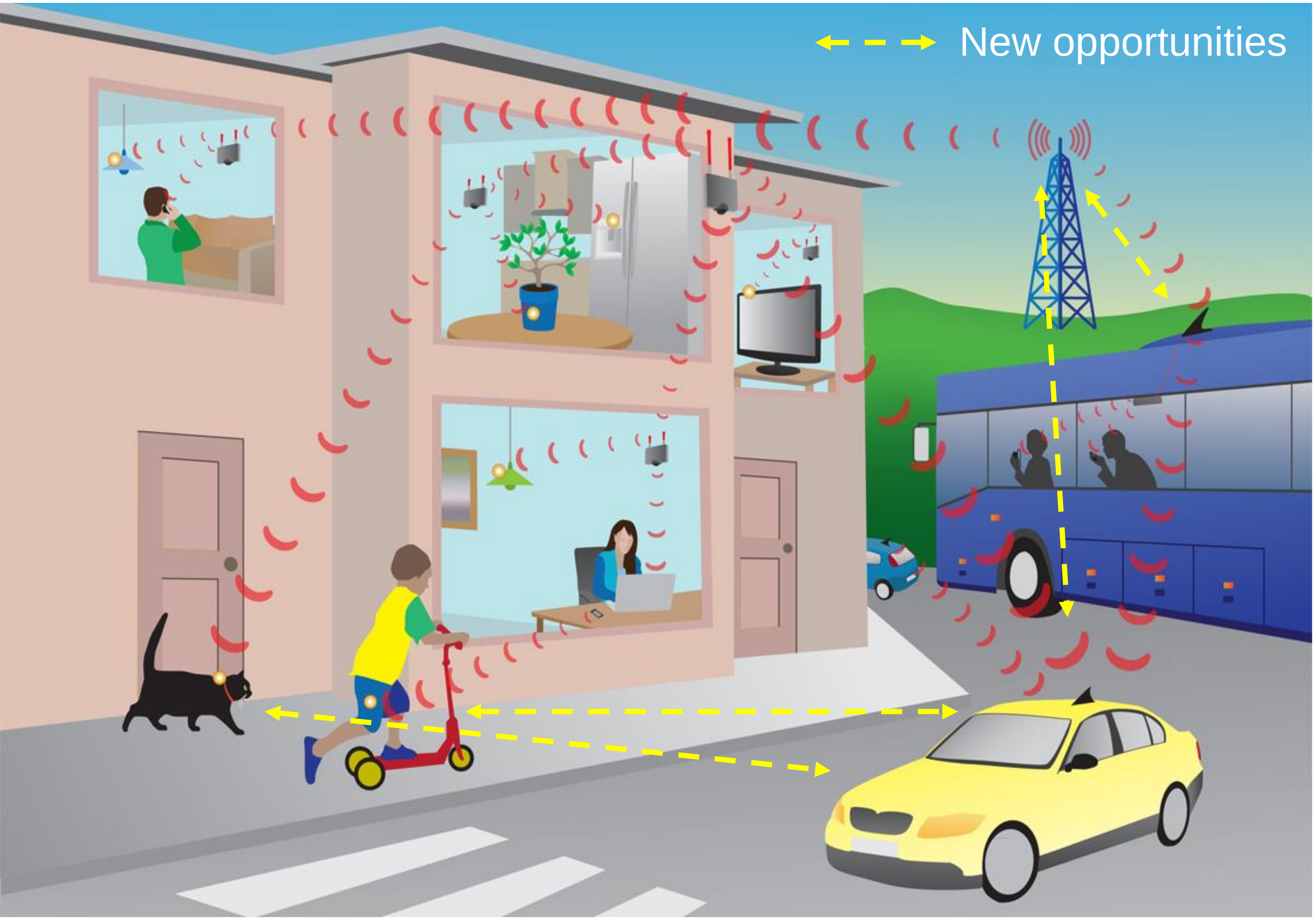


Source: mmMAGIC WP4 presentation, ETSI workshop, Sophia-Antipolis, Jan 28, 2016

Network slicing - Where should we do the computing?



Challenges and Opportunities with Demanding Verticals ”Integrated Moving Networks”



- **<u>Mutual benefits!</u>**
- **Better mobile systems efficiency**: Vehicles collect side information to improve the resource allocation and performance of the mobile network
- **More reliable V2X links**: Connect non-vehicular users to the Traffic Safety/Traffic Efficiency protocols (Pedestrians, cyclists, pets, …)
- **New disruptive business opportunities:** exploiting vehicle sensed data

The research leading to these results partly received funding from the European Commission H2020 programme under grant agreement no671650 (5G-PPP mmMAGIC project).

THANK YOU!

Find out more at https://5g-mmmagic.eu

Public deliverables: https://5g-mmmagic.eu/results/#deliverables

D1.1: "Use cases characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz", released 2015-11-30
D5.1 "Initial multi-node and antenna transmitter and receiver architectures and schemes" released 2016-03-31
D4.1 "Preliminary radio interface concepts for mm-wave mobile communications", released 2016-06-30
D3.1 "Initial concepts on 5G architecture and integration", released 2016-03-31
D2.1 "Measurement campaigns and initial channel models for preferred suitable frequency ranges", released 2016-03-31

mmMAGIC

6th Globecom'2017 Workshop on International Workshop on Emerging Technologies for 5G and Beyond Wireless and Mobile Networks (ET5GB)

Mon or Fri Dec 4 or 8, 2017, Singapore

Main topics:

- Novel radio access network (RAN) architectures
- Advanced radio resource management (RRM) techniques
- Emerging technologies in physical layer
- Novel services
- mmWave communications
- Energy efficiency
- Spectrum
- Prototype and test-bed for 5G and beyond technologies

Workshop Chairs:

- Wei Yu, University of Toronto, Canada
- Tommy Svensson, Chalmers U. of Technology, Sweden
- Lingjia Liu, University of Kansas, USA

Technical Program Chairs:

- Halim Yanikomeroglu, Carleton University, Canada
- Charlie (Jianzhong) Zhang, Samsung Electronics, USA
- Peiying Zhu, Huawei Technologies, Canada

http://wcsp.eng.usf.edu/5g/2017 (to appear) http://wcsp.eng.usf.edu/5g/2016

http://www.ieee-globecom.org/

From concept to deployment: the visions of the 5GCHAMPION and 5G-MiEdge projects

(Olympic Games are coming ...)

Valerio Frascolla
Intel

2017.04.27, COCORA 2017, Venice

5GCHAMPION (www.5g-champion.eu)

- *Project name: 5G Communication with a Heterogeneous, Agile Mobile network in the Pyeongchang Winter Olympic Competition*

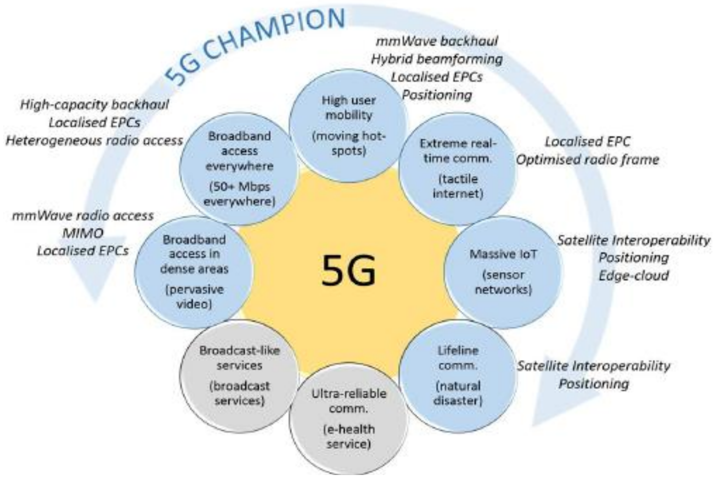
- *Funding scheme: FP8, Europe-Korea co-funding*

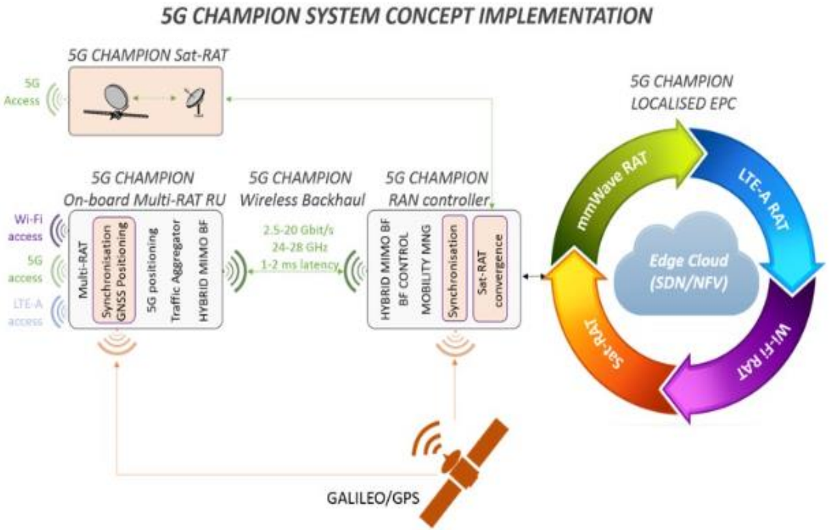
- *Duration: 2016.06 – 2018.05*

- *Key Targets:*
  - The first 5G proof-of-concept in conjunction with the 2018 Korean Winter Olympics,
  - Synergize satellite and terrestrial technologies,
  - Strong impact on Standards bodies.

Europe	Rep. of Korea
1. CEA-Leti (Coordinator), France	1. ETRI (Coordinator)
2. Nokia, Finland	2. Seoul Metropolitant Rapid Transit
3. Intel, Germany	3. South Korea Telecom
4. Thales Alenia Space, France	4. HFR
5. University of Oulu, Finland	5. Clever Logic
6. Fraunhofer HHI, Germany	6. Seoul National University
7. Telespazio, France	7. Dankook University
8. iMinds, Belgium	8. Hanyang University
	9. Korea Telecom
	10. Eluon
	11. InSoft
	12. Mobigen
	13. Gwangju Institute of Science and Technology

5GCHAMPION

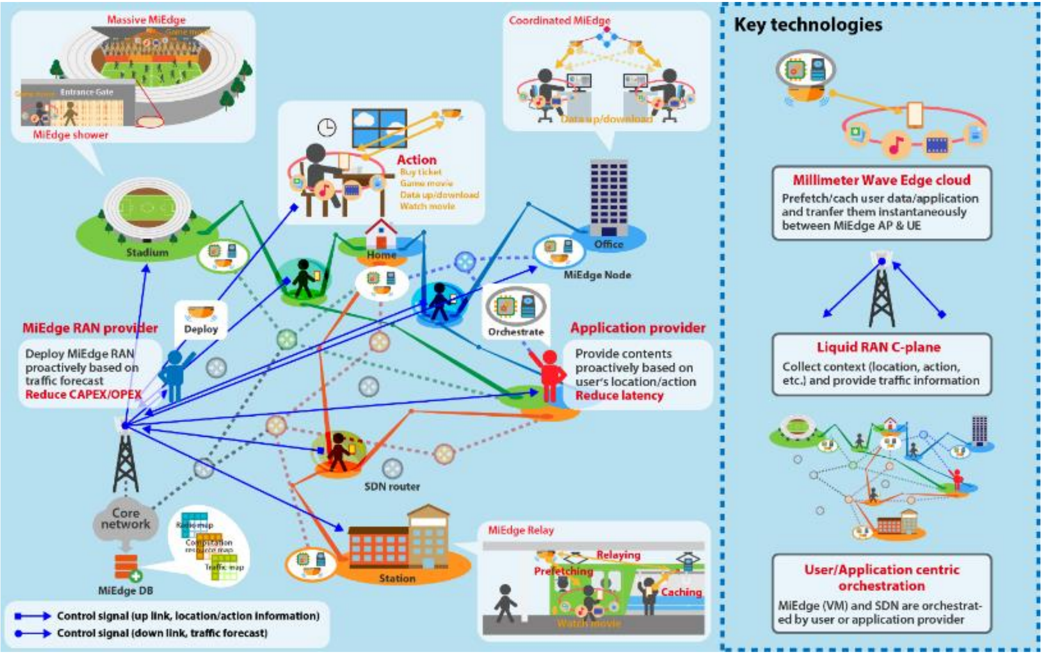




- *Main technology enablers:*
  - mmWave Backhauling,
  - mmWave transceivers with reconfigurable antennas,
  - Localised evolved packet core supported by distributed or centralized mobile edge clouds with caching,
  - Media streaming functionalities,
  - Satellite radio access,
  - Satellite-terrestrial positioning.

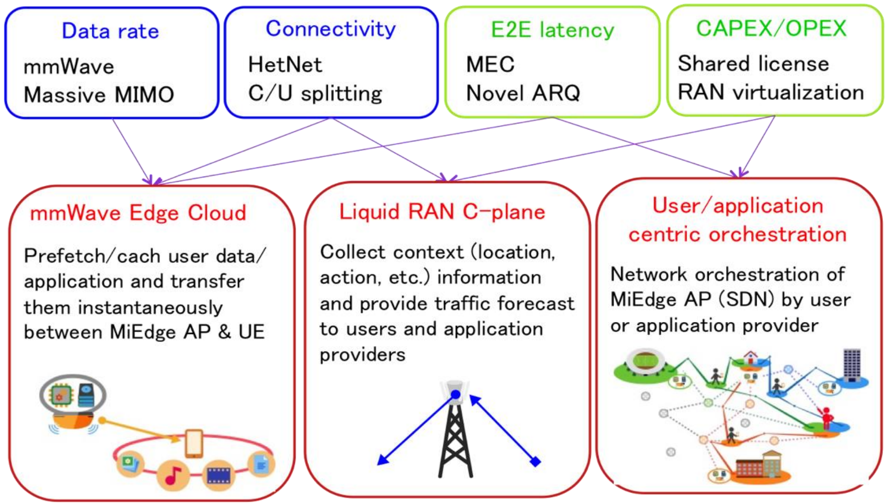
5G-MiEdge (5g-miedge.eu)

- Name: Millimeter-wave Edge Cloud as an Enabler for 5G Ecosystem
- Funding scheme: FP8, Europe-Japan co-funding, 2016.06 – 2019.05
- *Key Target:*
  - 5G proof-of-concept in conjunction with the 2020 Japanese Summer Olympics.
- *Key technology enablers:*
  - mmWave Access & Backhaul,
  - User/Application Centric Orchestration,
  - Liquid RAN Control-plane:
    - novel ultra-lean and inter-operable control signaling over 3GPP LTE to provide liquid ubiquitous coverage in 5G networks, based on acquisition of context information and forecasting of traffic requirements.

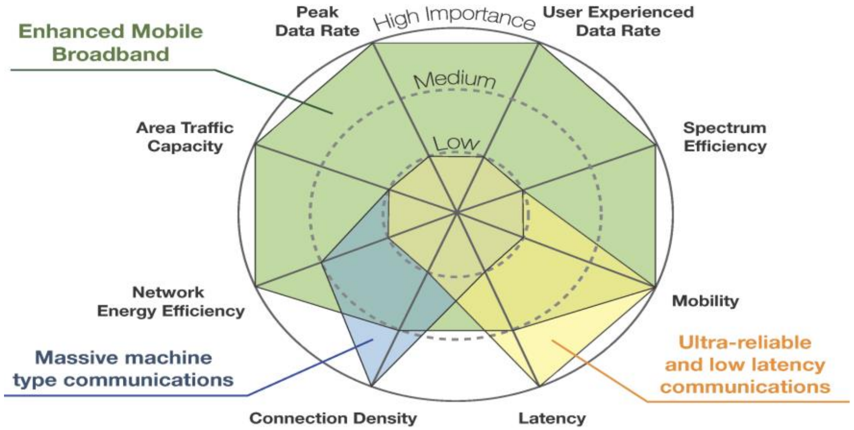


5G-MiEdge

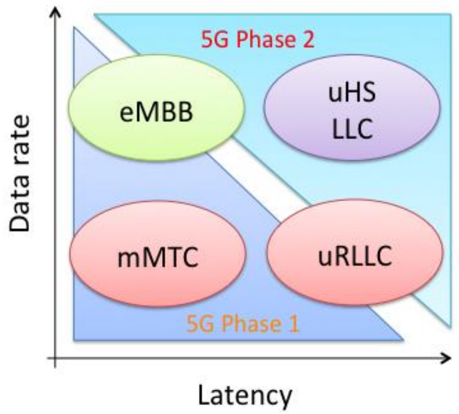
- Main research directions:
  - Focus on the ultra High-Speed and Low Latency Communications (uHSLLC) use cases and related technology enablers
  - Synergize between mmWave and MEC technologies



Technology enablers for uHSLLC and related KPIs



5G KPI defied in IMT-2020



Q&A

➢ Questions?

Disclaimers

5G-MiEdge: The research leading to these results are jointly funded by the European Commission (EC) H2020 and the Ministry of Internal affairs and Communications (MIC) in Japan under grant agreements N° 723171 5G MiEdge in EC and 0159-{0149, 0150, 0151} in MIC.

5GCHAMPION: The research leading to these results was supported by the Institute for Information & communications Technology Promotion (IITP) grant, funded by the Korea government (MSIP) (No.B0115-16-0001, 5GCHAMPION), and received funding from European Union H2020 5GPPP under grant n. 723247.

Intel Communication and Devices Group

5G for people and things
Key to the programmable world

Overview

5G Radio Interface

- Worldwide cm and mm bands to enable Gbps user rates. [Revolution]
- Massive MIMO technologies to help cm and mm wave technologies. [Revolution]
- Performance Results
- Dynamic TTI [Evolution]
- Multi-connectivity xRAT [Evolution]

5G IoT

- Cat-M and NB-IOT [Evolution]
- New air inteface to optimize IOT? [Revolution]

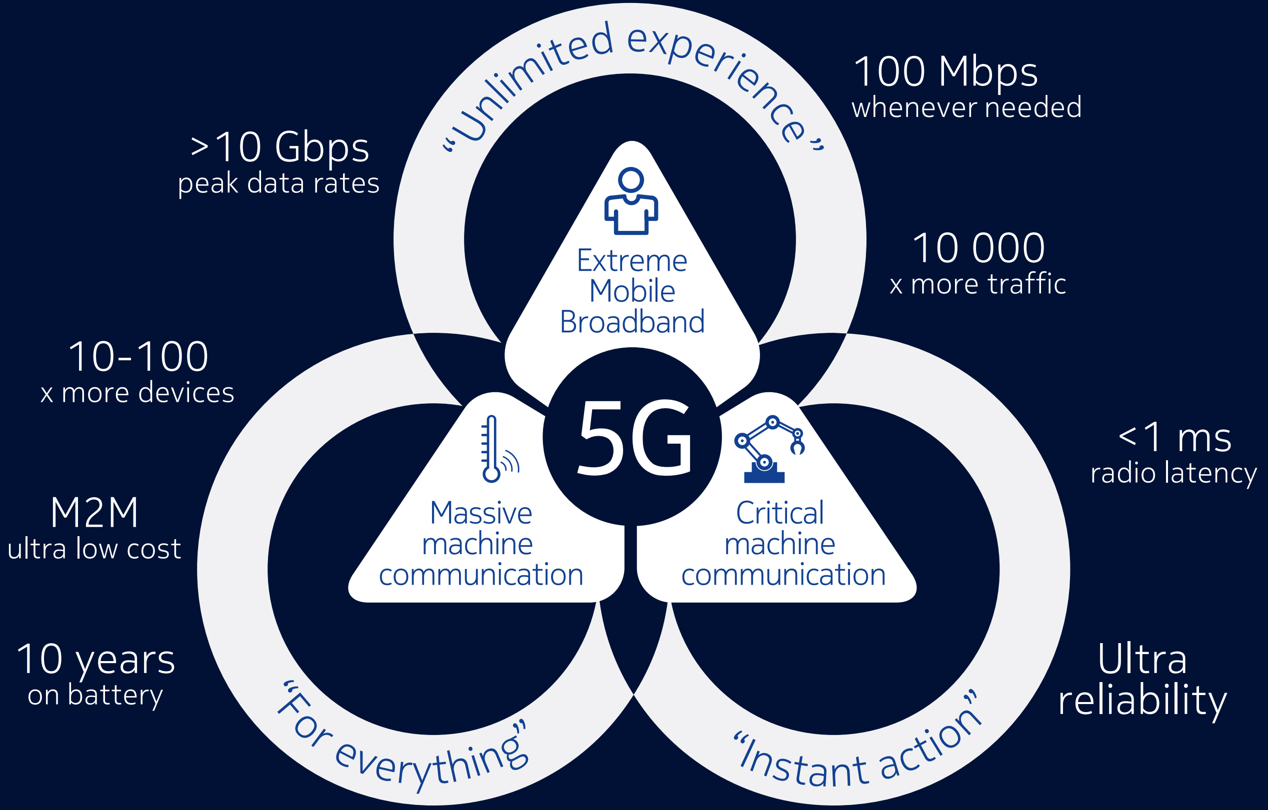
5G Networking

- Network slicing [Evolution]
- Flexibility [Revolution]

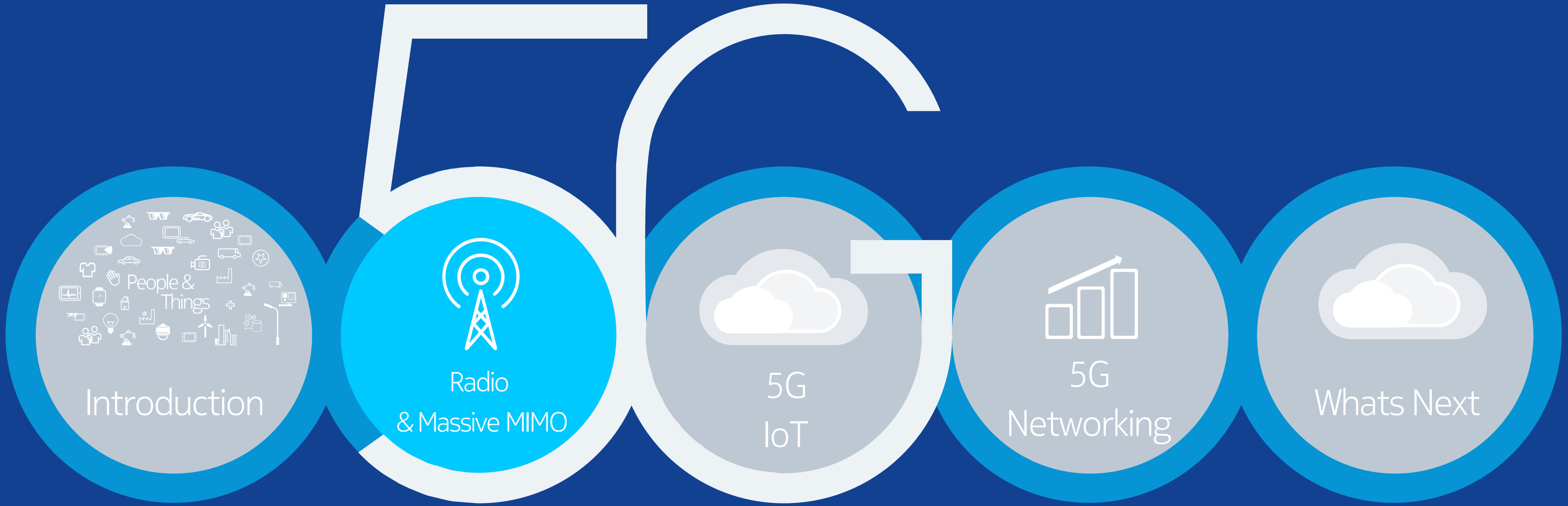
5G involves two things: **what** we innovate on and **how** we do it.

NOKIA

Diverse requirements [MBB vs IoT]



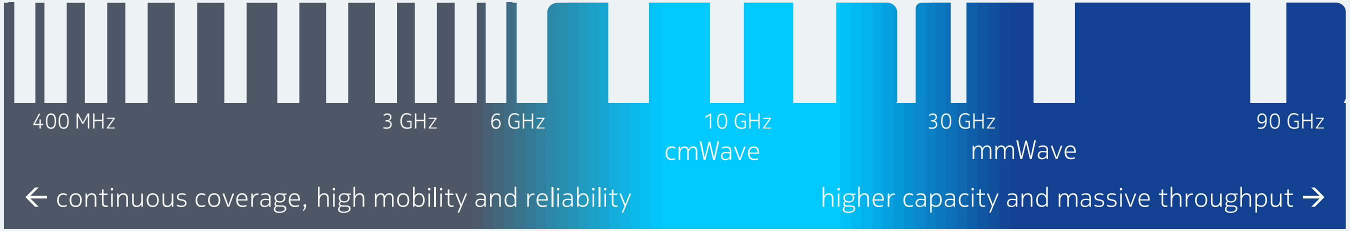
public
NOKIA



Key to the programmable world

Unlocking new spectrum assets | Foundation for 5G

Leveraging all bands , ranging from ~400MHz - 100GHz



Different characteristics, licensing, sharing and usage schemes

Carrier BW — n * 20MHz — n * 100 MHz — 1-2GHz

Duplexing — FDD — TDD

Cell size: Macro, Small, Ultra small

Coverage ← → Capacity

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | ultra low | 10 years

Leading METIS I & II spectrum work package

Leading modeling know-how
Channel measurements from 3-73GHz

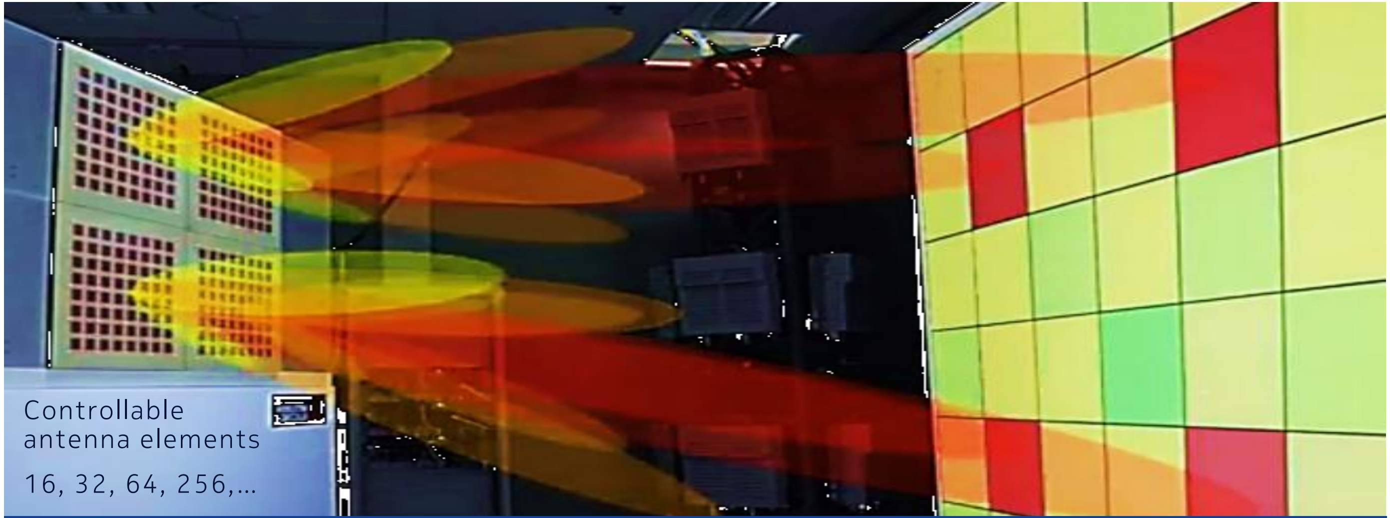
World's 1st trials
on shared spectrum access

  public

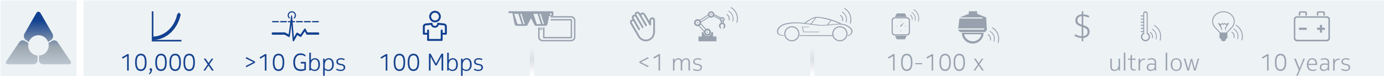
NOKIA

Native massive MIMO | Let the capacity follow the demand

Chip-scale antennas, high beamforming & multiplexing gain



Exploiting high frequency bands with chip scale antenna array research
→ Compensating path loss with high antenna gain



700%
Cell edge gain

+80%
Spectral efficiency

Cooperation with top notch industry and university partners

mmWave trials
with DOCOMO

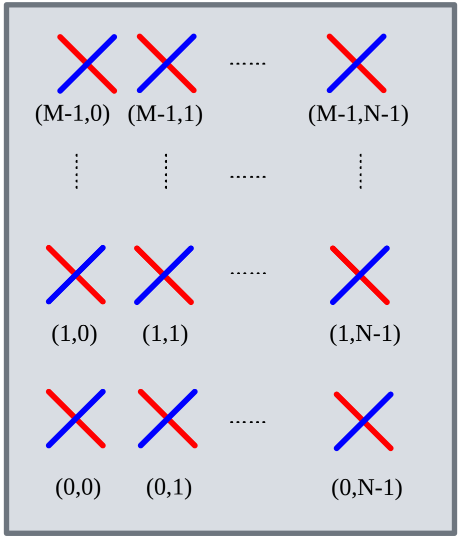
10Gbps speed record
w. National Instruments

public

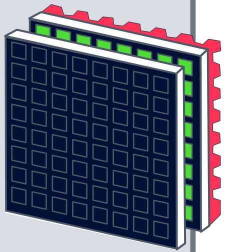
NOKIA

What is "Massive MIMO"?

- **Massive MIMO** is the **extension of traditional MIMO** technology to antenna arrays having a **large number** of **controllable antennas**



- MIMO = Multiple Input Multiple Output = **any transmission scheme involving multiple transmit and multiple receive antennas**
  - Encompasses all implementations:
    - RF/Baseband/Hybrid
  - Encompasses all TX/RX processing methodologies:
    - Diversity, Beamforming, Spatial multiplexing,
    - SU & MU, joint/coordinated transmission/reception, etc.
- **Massive ➔ Large number**: >> 8
- **Controllable antennas**: antennas (whether physical or otherwise) whose signals are adaptable by the PHY layer (e.g., via gain/phase control)



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Why "Massive MIMO"

- Benefits:
  - **Enhance Coverage ➔** High gain adaptive beamforming
    - Focus energy more towards the user, increase SINR
  - **Enhance Capacity ➔** High order spatial multiplexing
    - Multiple parallel spatial streams to a single user (SU) or to multiple users (MU)
- Relevance to 5G:
  - Lower operating frequencies (e.g., <6GHz) are more interference limited
    - LTE already designed for high spectral efficiency (<8 Antenna ports)
    - **Capacity-enhancing solutions become essential**
  - Higher operating frequencies (e.g., >>6GHz) have poor path loss conditions
    - **Coverage-enhancing solutions become essential**

Signal Processing View: Fully Connected Arrays

Baseband

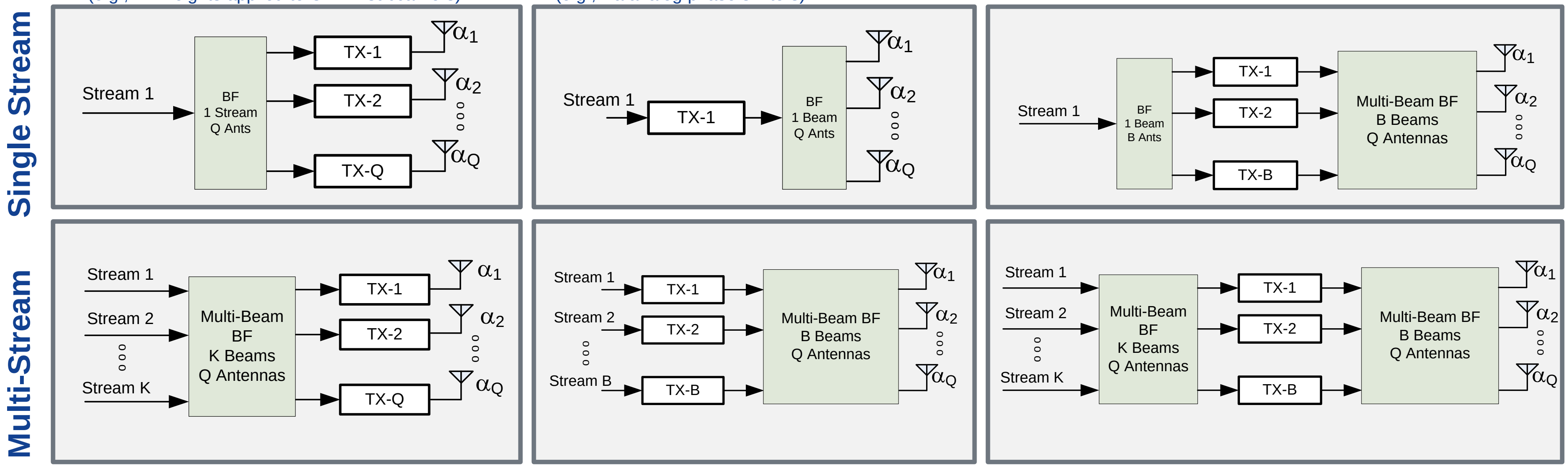
Frequency selective weights applied at baseband
(e.g., BF weights applied to OFDM subcarriers)

RF

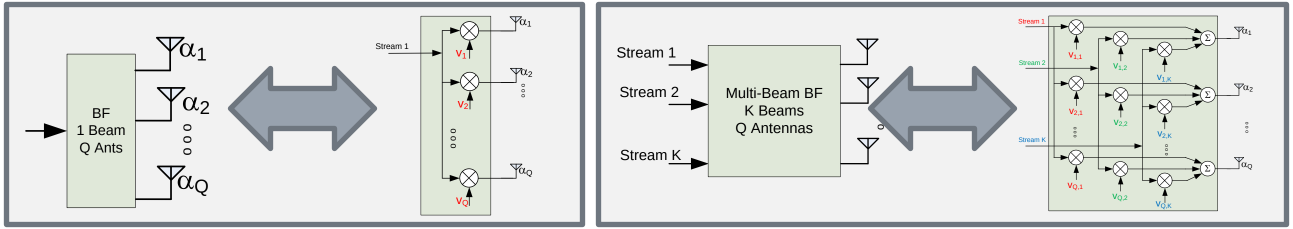
Frequency non-selective weights applied at RF
(e.g., via analog phase shifters)

Hybrid

TX weights applied at both RF and baseband



Legend:



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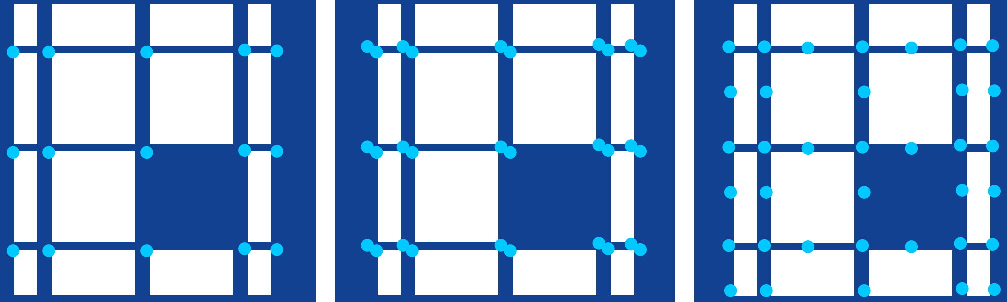
RF vs. Baseband vs. Hybrid Architectures

Baseband	RF	Hybrid
Adaptive TX/RX Weightings at Baseband	Adaptive TX/RX Weightings at RF	Adaptive TX/RX Weightings at both RF and Baseband
Single transceiver Per Antenna Port	Single transceiver per RF beam	Single transceiver per RF beam
“Frequency-Selective” Beamforming	“Frequency-Flat” Beamforming	Combination RF / Baseband
High Flexibility	Low Flexibility	Moderate Flexibility
High power consumption & cost characteristics	Better power consumption & cost characteristics	Good power consumption & cost characteristics

Performance of Massive MIMO @ mmWave
5G requirements can be met even in challenging environments



75 AP/km^2 — 150 AP/km^2 — 187 AP/km^2 → AP density

75 AP/km^2	150 AP/km^2	187 AP/km^2
2.1 Gbps Average UE Throughput	4.1 Gbps Average UE Throughput	5.1 Gbps Average UE Throughput
<1 Mbps Edge Throughput	222 Mbps Edge Throughput	552 Mbps Edge Throughput
16.4% Outage Probability	3.2% Outage Probability	1% Outage Probability

→ Network capacity

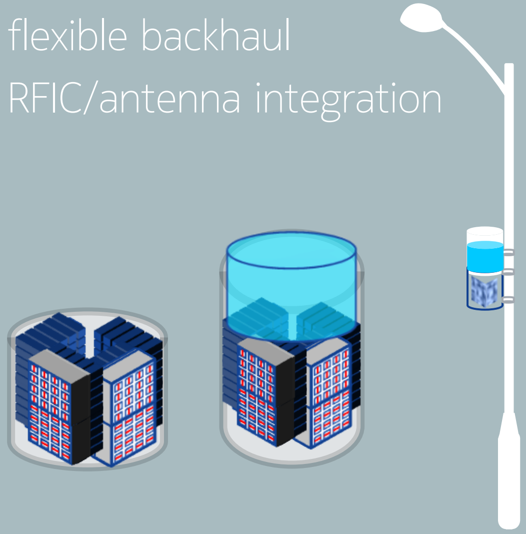
Multi-connectivity (72GHz / 2GHz BW)

Outage = less than 100Mbps throughput

Performance in outdoor environments

Enabled through

- flexible backhaul
- RFIC/antenna integration



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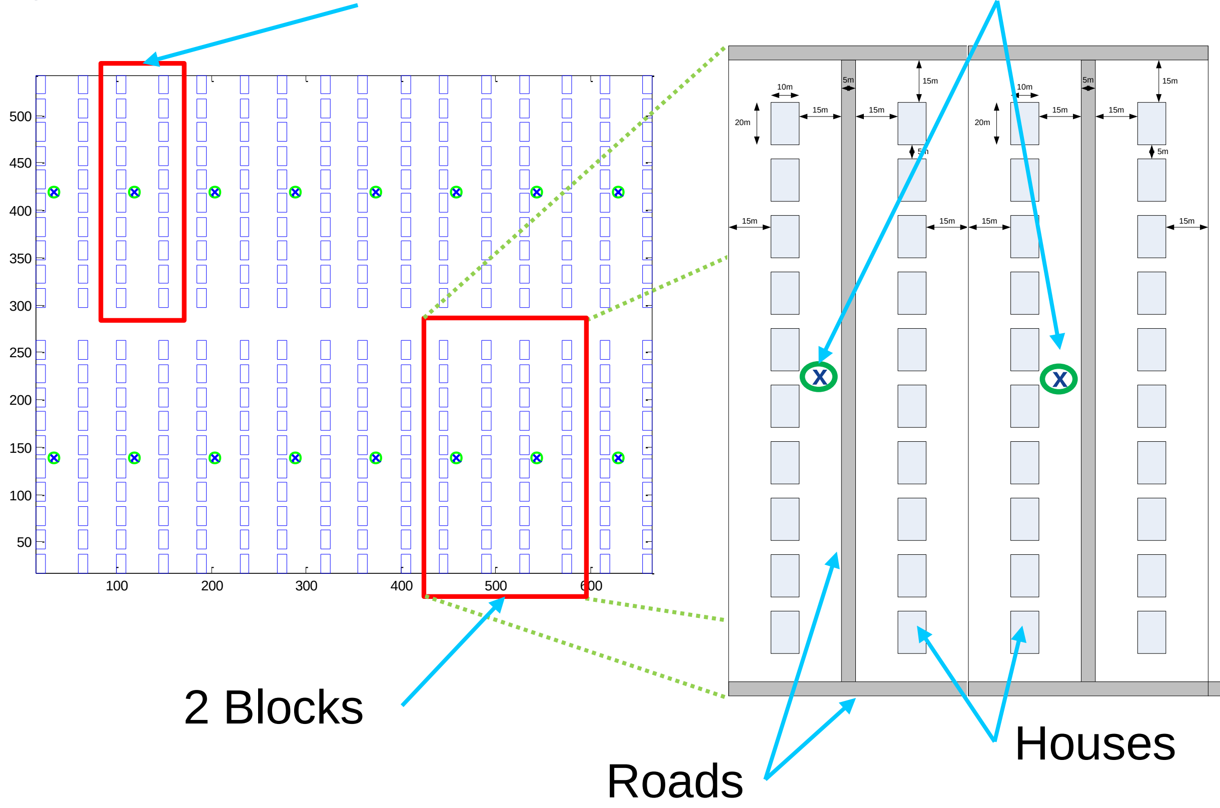
Wireless 5G to the Home at 39GHz

- Physical Layer Simulation Study

- Modified Detailed 3GPP/RAN1 physical layer system level simulator
- Suburban neighborhood layout of 320 houses, 16 blocks, 1 AP per block
- AP is either a single omni sector site or is a 3-sector site mounted on 6m high lamppost
- 10 active CPEs per AP site
- Indoor CPEs vs Outdoor CPEs
- Path Loss, Blockage, and Multipath Modeling appropriate for 39GHz
- Null Cyclic Prefix Single Carrier System with 800MHz Bandwidth



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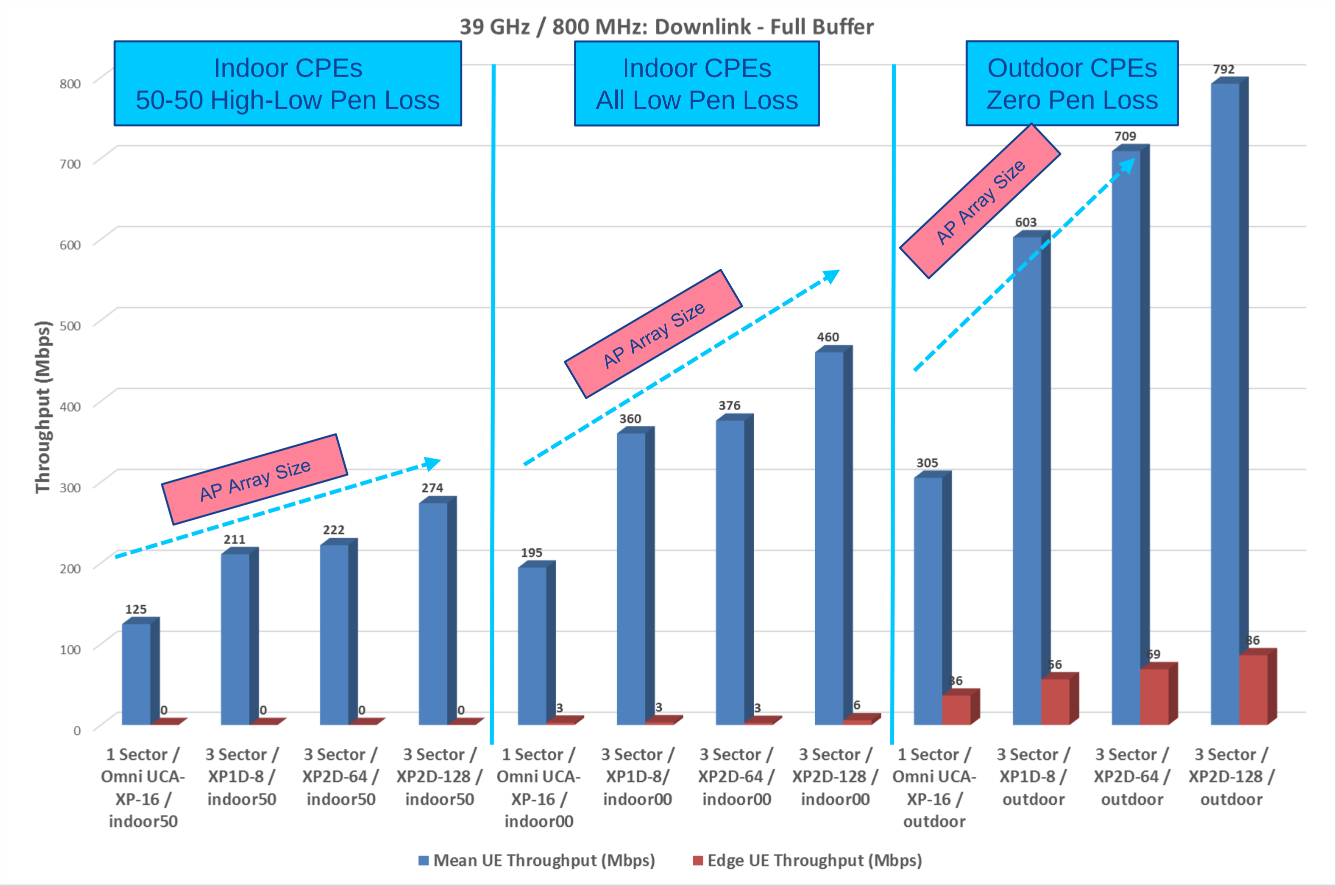
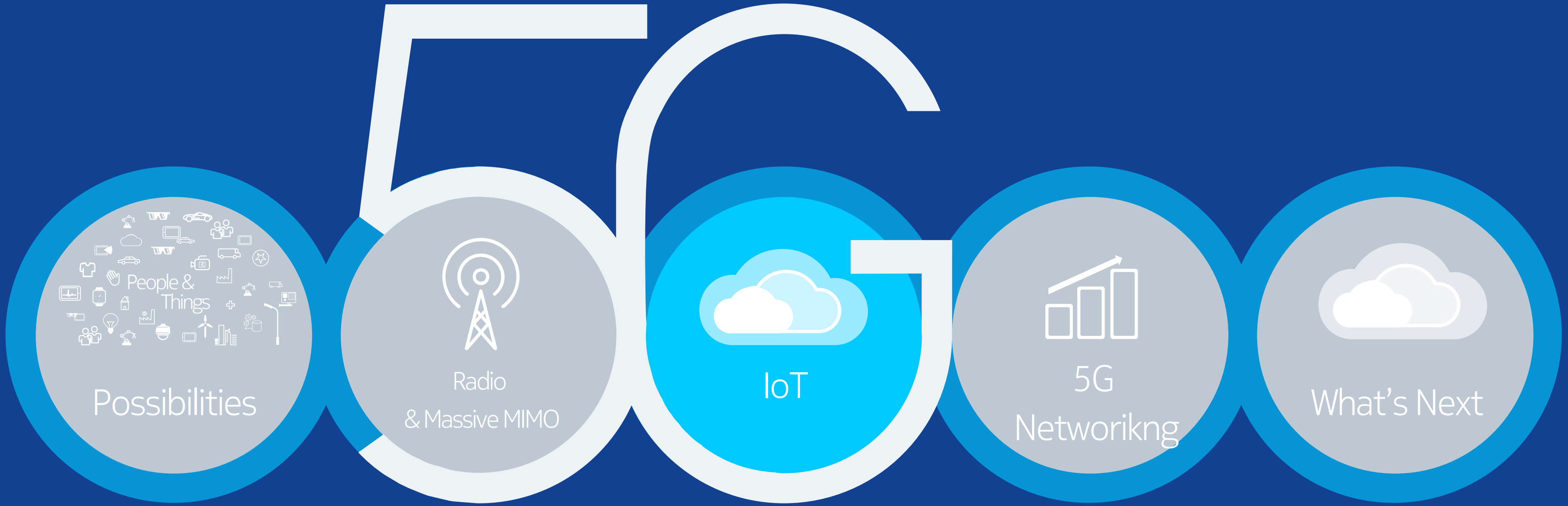
39 GHz NCP-SC, 800 MHz BW – Effect of Larger Antenna Arrays and Penetration Loss

- AP Arrays:
  - 1 Sector: Omni UCA-XP, **16** antennas
  - 3-Sector: XP1D, **8** antennas
  - 3-Sector: XP2D, **64** antennas
  - 3-Sector: XP2D, **128** antennas
- CPE: 2 antennas (omni)
- Antenna element gain:
  - For 1D arrays: antenna element gain = 14dBi
  - For 2D arrays: antenna element gain = 1dBi
- 10 CPEs per site on average





Key to the programmable world

IoT | Low cost & power for massive machine type communication

LTE-M for small, infrequent & low cost data transfer

Power saving

Longer sleeping cycles*

Less signaling for wakeup

Power Save Mode

Simplified modems

Narrowband transmission

Reduced transmit power

Limited downlink transmission modes

UE processing relaxations

…

4 x coverage

compared to current LTE

New coding

Repetition and power spectral density boosts

+15~20 dB coverage

>10 years

Battery life with two AA batteries

Very low device cost

Live trial with KT

MWC 2015

First live demo

on commercial Nokia FlexiZone and core

Driving for availability in 3GPP Rel.13, 2016

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | $ | ultra low | 10 years

*) Extended Discontinuous Reception (DRX)

public

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Main LTE-M & NB-IoT features

- 3GPP specifications in Release 12 and 13

Release 12 introduced low complexity UE category (“Cat-0”) with lower data rate, half duplex and single antenna.

Release 13 will further reduce UE device complexity with narrowband RF and lower peak data rates.

3GPP LTE	Release 8	Release 8	Release 12	Release 13	
UE characteristics	**Cat. 4**	**Cat. 1**	**Cat. 0**	**Cat. M**	**NB-IoT**
Downlink peak rate	**150 Mbps**	**10 Mbps**	**1 Mbps**	**1 Mbps**	**200 kbps**
Uplink peak rate	**50 Mbps**	**5 Mbps**	**1 Mbps**	**1 Mbps**	**144 kbps**
Number of antennas	2	2	1	1	1
Duplex mode	Full duplex	Full duplex	Half duplex	Half duplex	Half duplex
UE receive bandwidth	20 MHz	20 MHz	20 MHz	1.4 MHz	200 kHz
UE transmit power	23 dBm	23 dBm	23 dBm	20 dBm	23 dBm
Maximum signal loss	**<140 dB**	**<140 dB**	**<140dB**	**156 dB**	**164 dB**
Modem complexity	100%	80%	40%	20%	<15%

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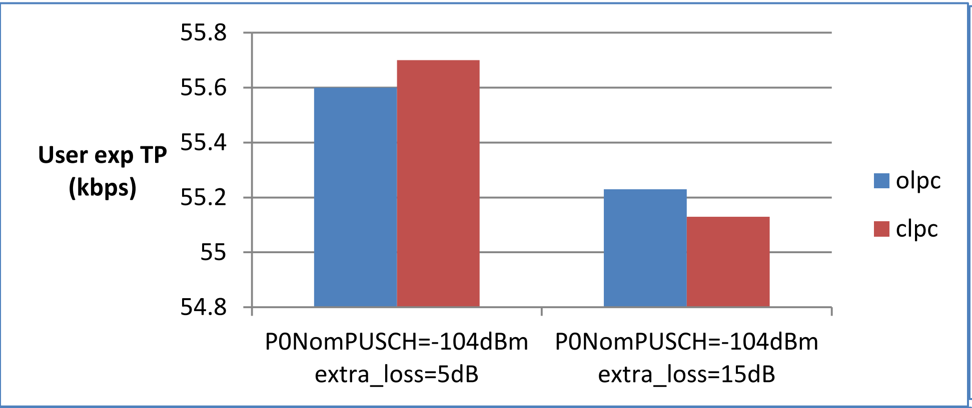
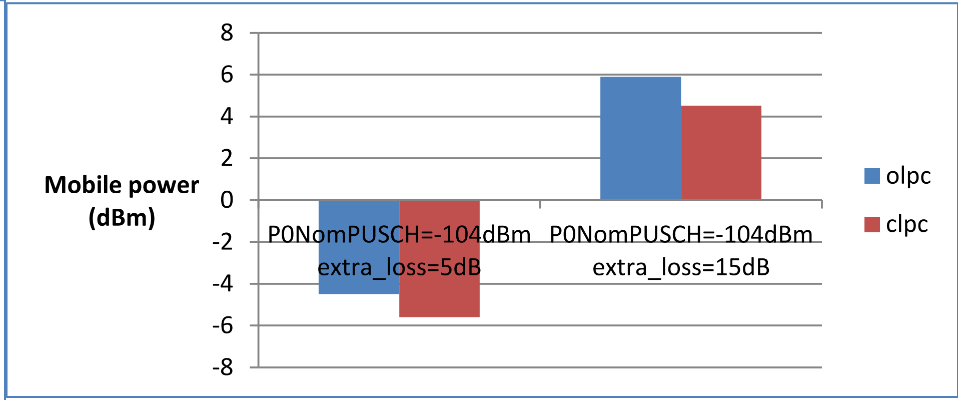
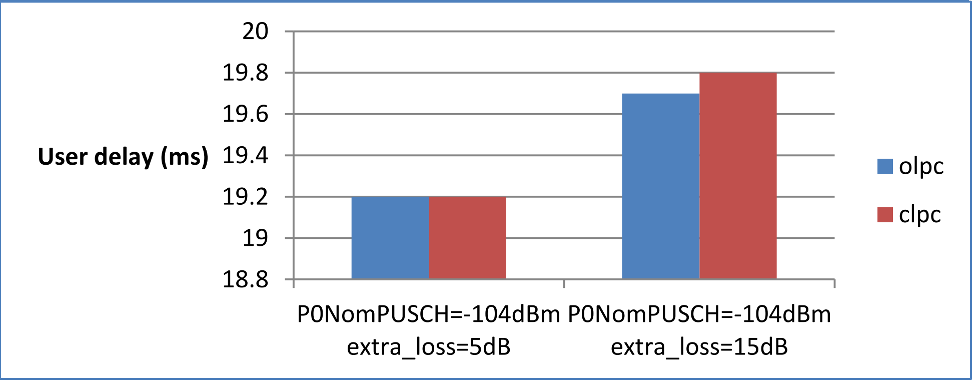
M-PUSCH Closed loop versus open loop (single cell)

- CLPC versus OLPC for a given P0NomPUSCH.







Performance is about the same between CLPC and OLPC. CLPC does seem to use lower transmission power.

OLPC has the about the same performance as CLPC in terms of throughput and delay but uses higher transmit power .

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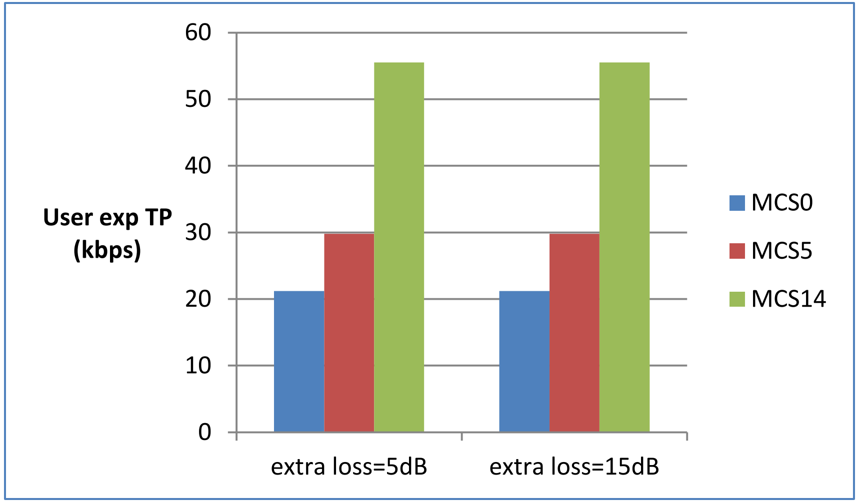
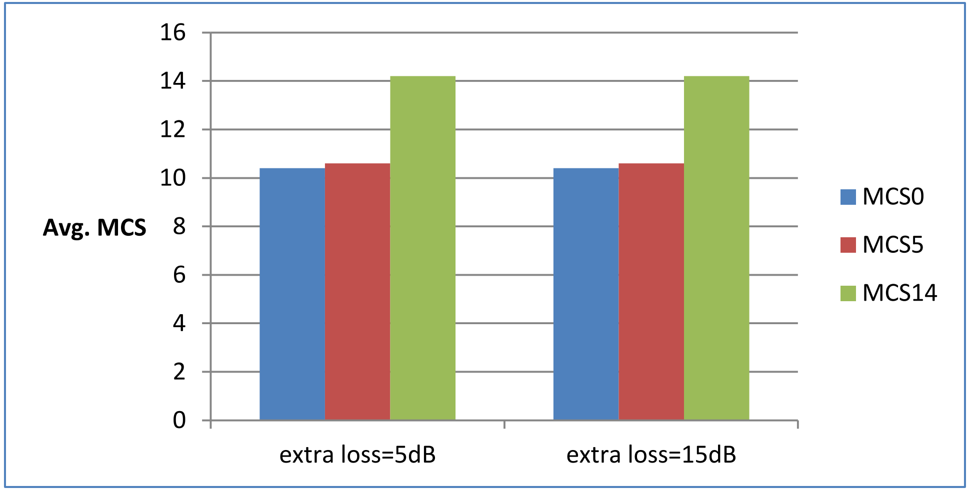
M-PUSCH - Impact of initial MCS(single cell)

- OLPC, PoNomPUSCH=-114dBm

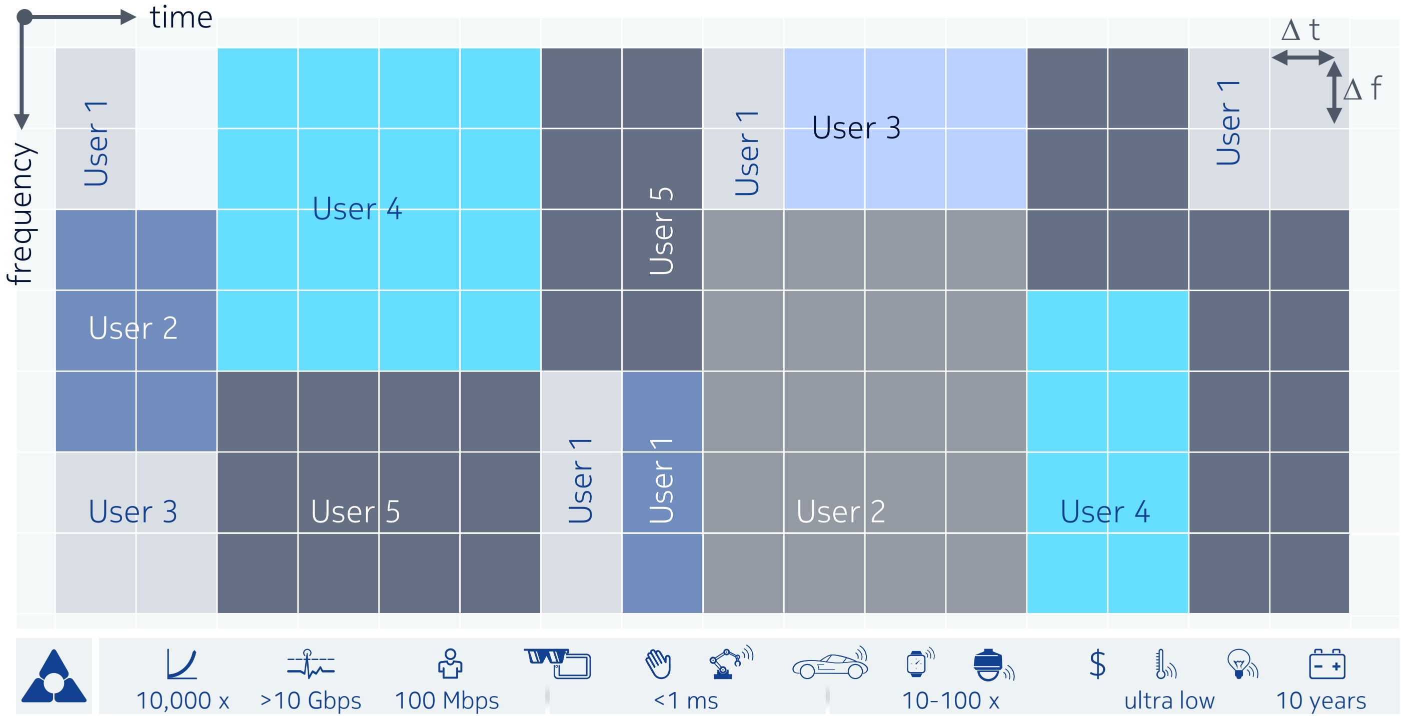




- Performance is sensitive to the initial MCS.
- Note: msg3 is not modeled here which could serve as a M-PUSCH measurement.

Initial MCS impacts performance .

Dynamic TTI: Flexibility in supporting MBB and IoT



*) compared to static TD-LTE

50-100% capacity gain*

Smart local traffic routing e.g. D2D on top of local cellular

SC/UDN low cost deployment e.g. via self-backhauling

Dynamic TDD cmW and mmW air IF blue prints and PoC

Part of eLA concept adopted in METIS

  public

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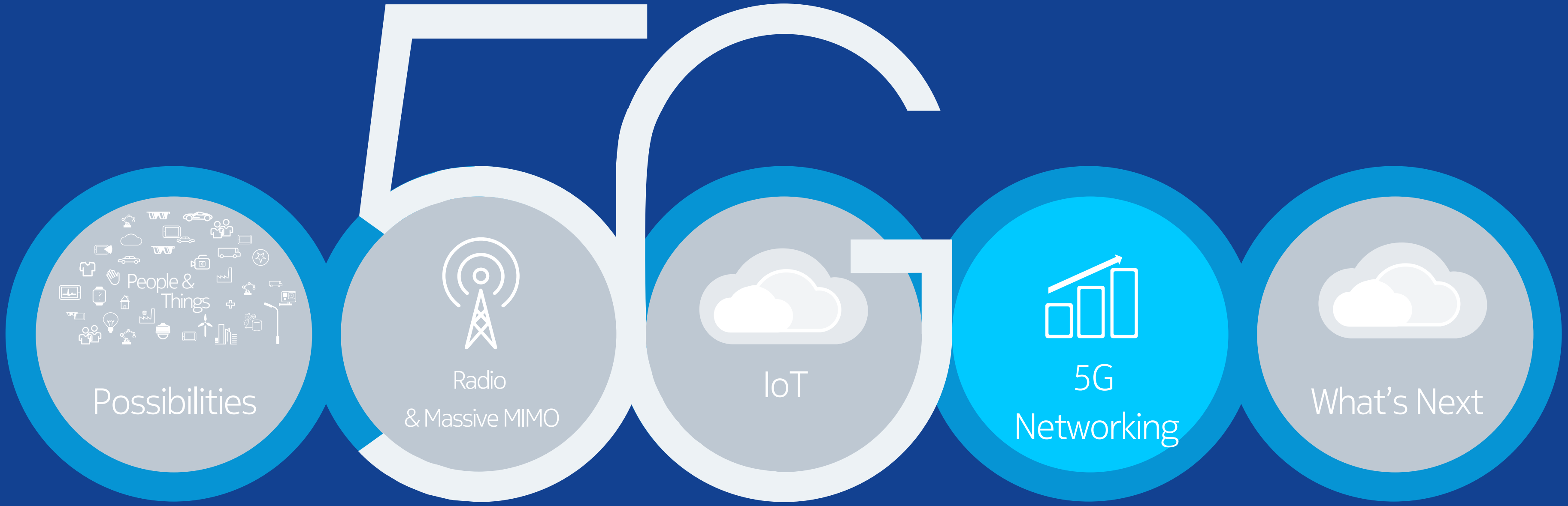

Key to the programmable world

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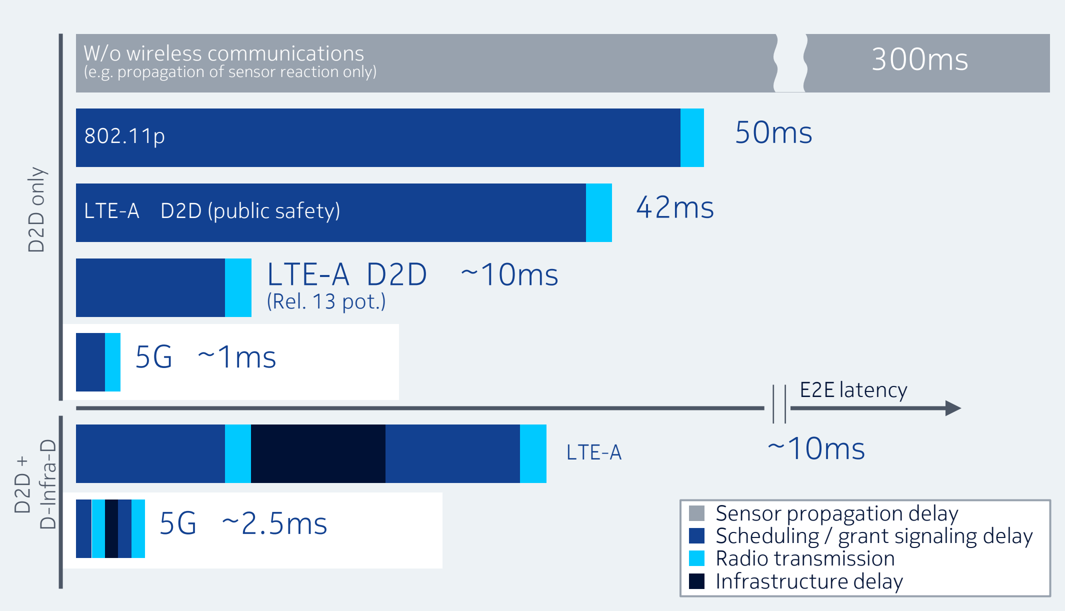
1ms Latency | Enabling a new generation of latency critical services

E2E latency aware scheduler

Latency optimized frame structure

Dynamic uplink-downlink

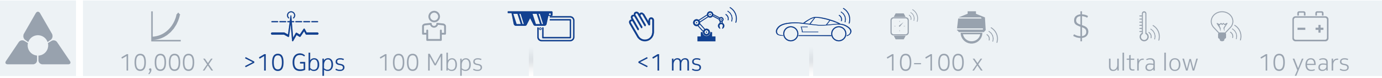
Pipeline processing



Autonomous driving and production

Tactile internet services

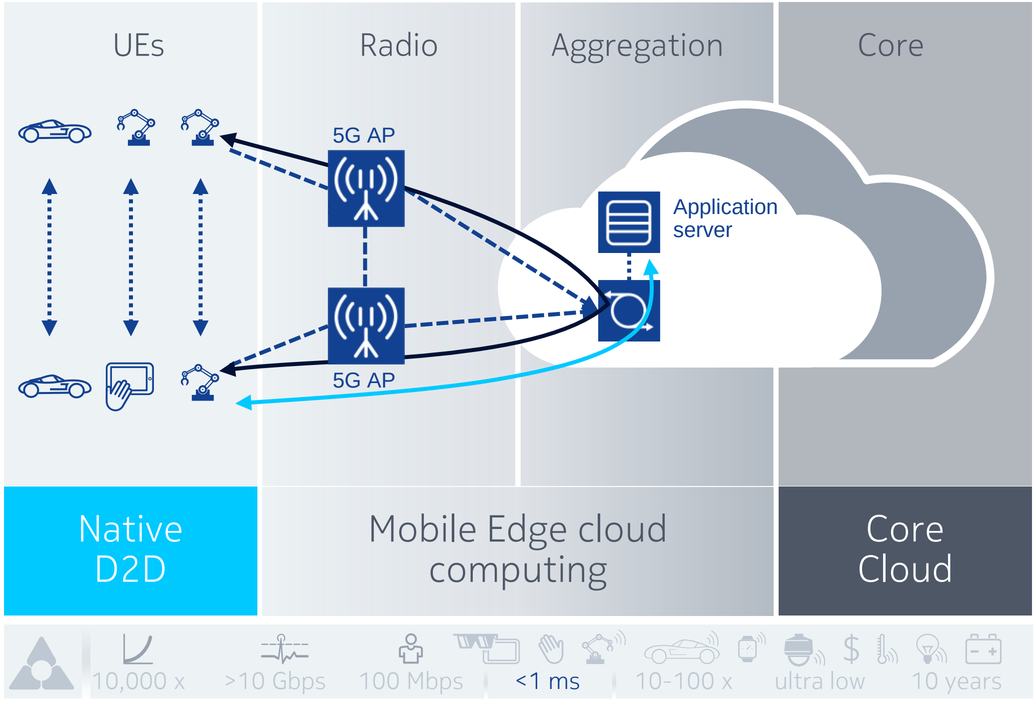
mmWave demo
with NTT DoCoMo



DMRS = Demodulation Reference Signal; GP = Guard Period

Fast traffic forwarding | Enabling a new generation of latency critical services

Lowest latency packet forwarding to UEs



Moving virtual networks

Mission-critical services, e.g. in V2X or industrial applications

Central cloud based	> 50 ms latency
Mobile Edge LTE	≈ 10 ms
5G Edge	≈ 2,5 ms
5G D2D	≈ 1 ms

Vehicle2Infra trial on German motorway

Pioneer in Mobile Edge Computing

Vehicle2Infra live demos

ETSI ISG Chair

  public

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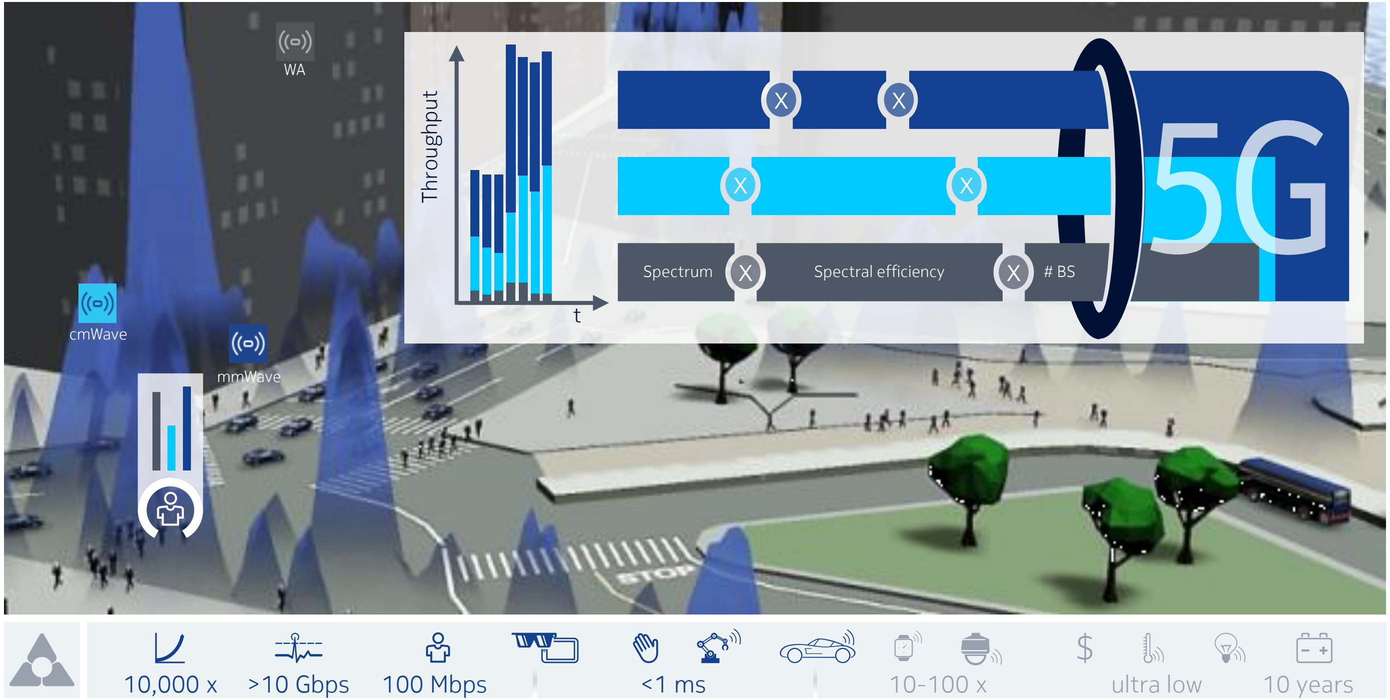
Multi-Connectivity | Perception of infinite capacity

Multiple radio technologies collaborating as one system



Extreme mobility robustness and ultra reliability

>100 Mbps anywhere

~ 3X burst throughput*

4G/5G real-time radio resource management know how built on demonstrator

*in example area, 50% load

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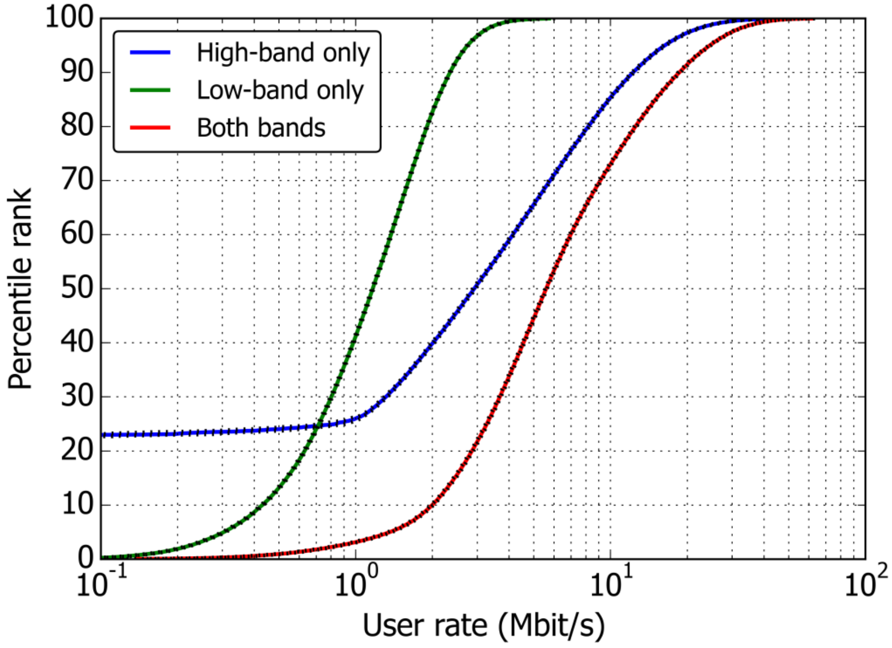
Multi-connectivity Gains

Opportunistically allowing mmwave to complement low band transmissions.



  public

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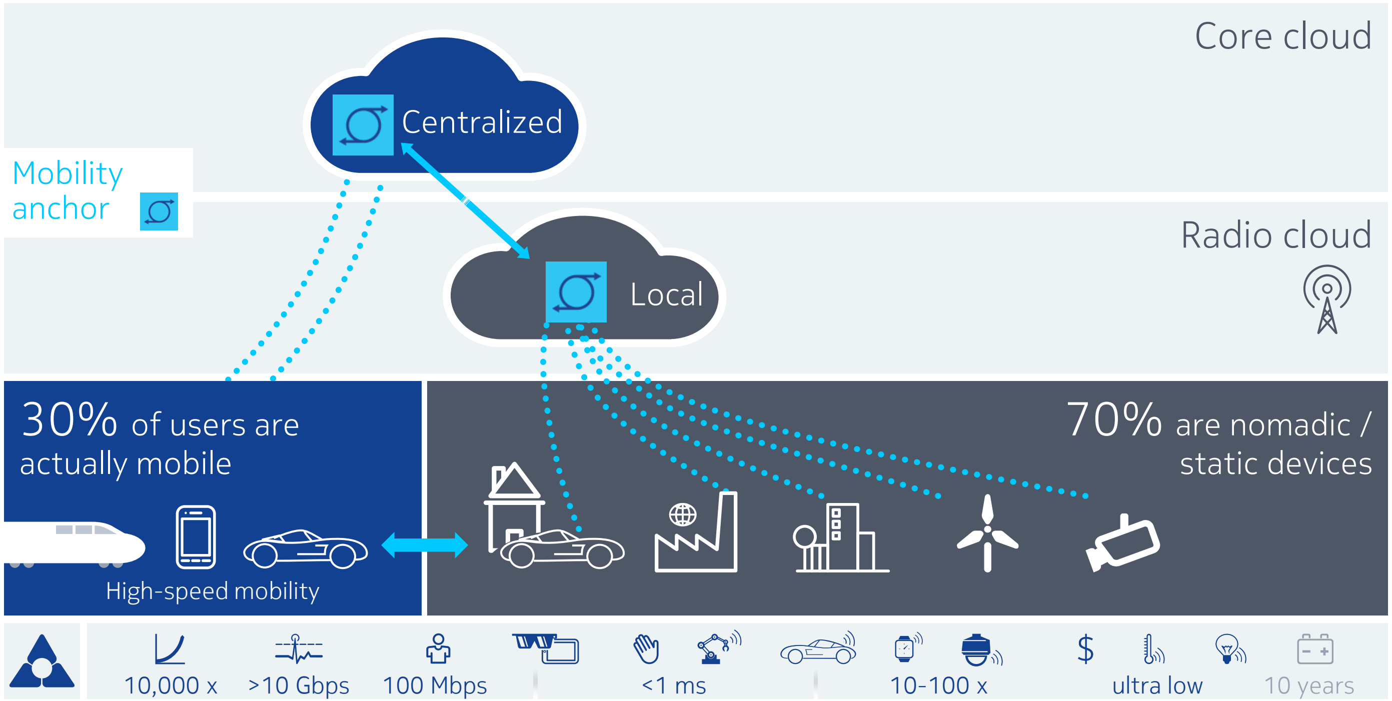
Mobility on demand | Highly efficient resource utilization

TCO optimized use of network resources



Less traffic backhauling to centralized cloud

TCO optimization

Best per service flexibility

Reduce core network resources

  public

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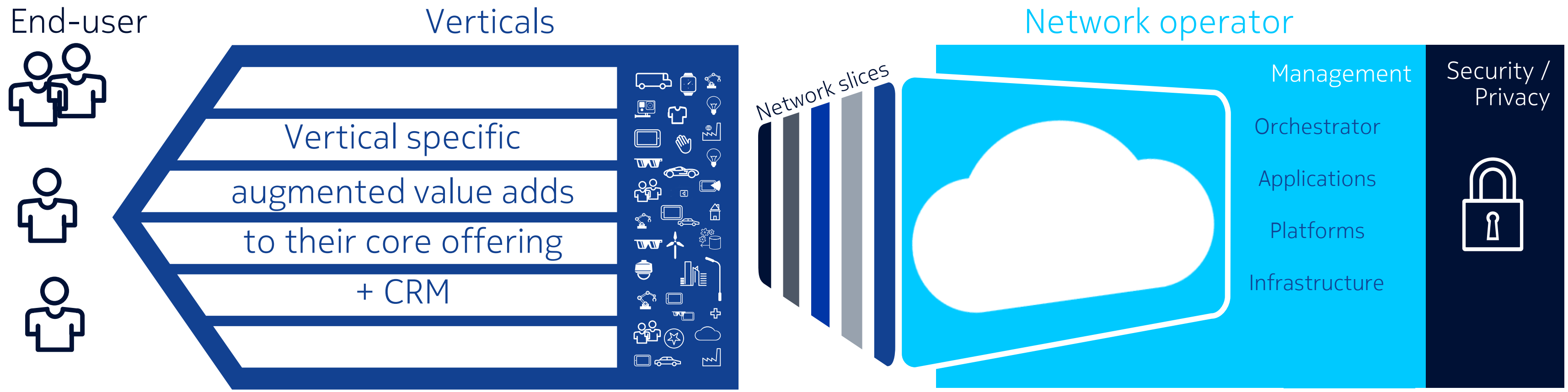
Network slicing

Help different industries to transform



KEY ENABLERS

- Slicing
- Dynamic Experience Management
- Any-to-any connectivity
- Low latency
- Slim radio for IoT

Network as a Service

Safety & Security | Mobile living | Utility & Energy | Traffic Mgmt. | Auto-motive | Health | Communi-cation | Logistics

Tailored vertical XaaS solutions

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Key milestones on the road to 5G – What's next?

2014

1st Brooklyn 5G Summit

- First 5G MWC showcase
- NTT DoCoMo cooperation
- MoU with CMCC/CMRI

2015

5G Radio demos

- 5G PPP projects started
- Positive outcome at WRC2015
- 3GPP standardization kicked off for 5G

2016

5G System demos

- 5G PPP projects in full swing
- 5G standardization on channel model, requirements and technology option selection

2017

Single RAN 5G System

- 3GPP 5G work in full progress
- IMT2020 evaluation process in ITU-R

2018

Pre standardized trials

PyeongChang 2018

- 5G phase 1 specs ready
- WRC2019 preparation underway
- Technology trials with key customers

2019

Pre commercial trials

- WRC19 outcome clear with new bands for IMT
- 5G phase 2 specs ready
- ITU-R process nearing completion

2020

Commercial network opened DOCOMO

TOKYO 2020

- Research on "6G" starts

+ Details

  public

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The Villages Amateur Radio Club

2015 Antenna Guide for The Villages

February 19, 2015

Antennas for The Villages

Tonight's review of the antenna members have used

Tonight's list of antennas will cover

- Multiband Antennas HF, 6M and some 2M/70cm
- Presenting the implementation for most used
- Description of layout with key PROs and CONs
- **This is a shopping list,** *not DIY which will be in future presentations*

Factors to be considered

This is not the end all list, but the important issues

- RF Radiation Efficiency
- Installation
- Stealthy-ness
- Impedance Matching
- Cost

Small Antennas are a Compromise
Stealth Antennas are a Compromise
Multiband Antennas are a Compromise

Antenna Design Rules

Pick one from the list below;

- You can make an HF antenna physically **small**
- You can make an HF antenna radiate **efficiently** at low angles
- You can make a **broadband** HF antenna with a wide VSWR Bandwidth

With the right compromises and some extra effort all three are possible

Modes & Bands

Compromise

Slicing a cake in such a way that everyone thinks they received the biggest piece!

The right planning requires each operator to think about which modes they want;

- SSB will require they best RF Efficiency available
- CW can operate on marginal RF Efficiency
- Digital can operate on marginal & poor RF Efficiency

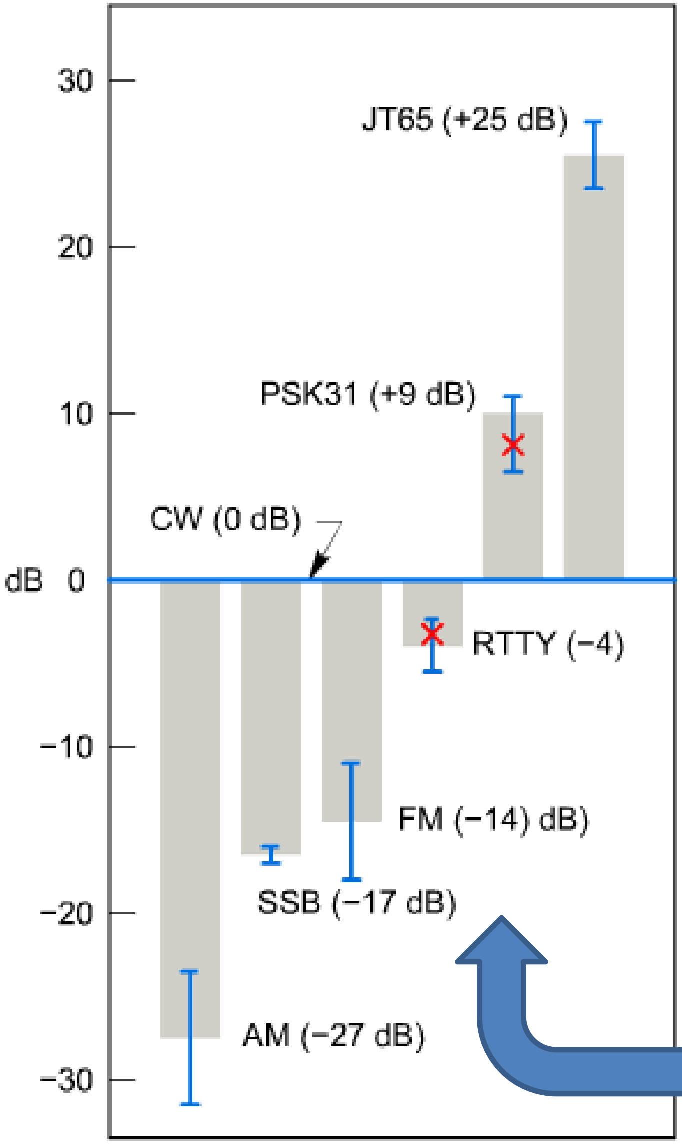
The right planning requires each operator to think about which bands they want;

- 160M & 80M
- 40M, 30M & 20M
- 17M, 15M, 12M, 10M & 6M

The right planning requires each operator to think about how each antenna presented can fit within your landscape

- Palms or Shade Trees?
- Villa Fences?
- Screen Enclosures?

How Much "Punch" Can You Get from Different Modes



QST Dec 2013, P30-32

"You can target the DX station's operating mode more confidently when you know CW can out perform unprocessed SSB by 17 dB and RTTY can out perform SSB by 11 dB. If you can't get them on phone, try RTTY or better still, try CW."

Table 1
Average Power for 100 W PEP Transmitter

Mode	Average Power (W)	Compared to CW (dB)
AM	25	−2.5
SSB	25	−2.5
FM	100	+3.6
RTTY	95	+3.3
CW	44	ref: 0
PSK31	75	+2.3
JT65	100	+3.5

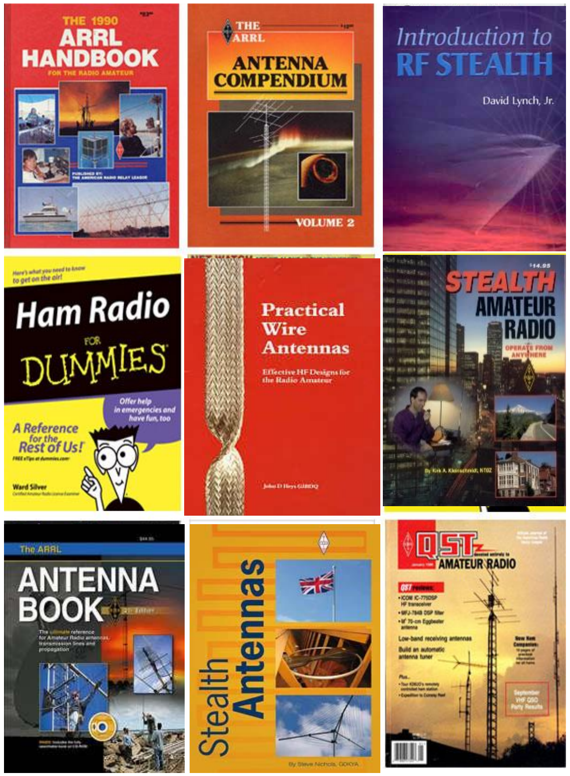
Table 2
Average Receiver Sensitivities

Mode	Receiver Sensitivity (microvolts)	Receiver Sensitivity (dBm)	Compared to CW (dB)
AM	0.72	−109.9	−25.1
SSB	0.22	−120.3	−14.7
FM	0.29	−117.7	−17.3
RTTY	0.096	−127.3	−7.7
CW	0.040	−135.0	ref: 0
PSK31	0.023	−139.8	+7.1
JT65	0.0035	−156.2	+21.2

Modes & Bands

Remember your mode is the dominant factor, then review the band performance to select your antenna. The important message is what is the “best” antenna for you is not the “best” for someone else!

Read every book on antennas or use Villages Antenna Guide to narrow the list



VS.

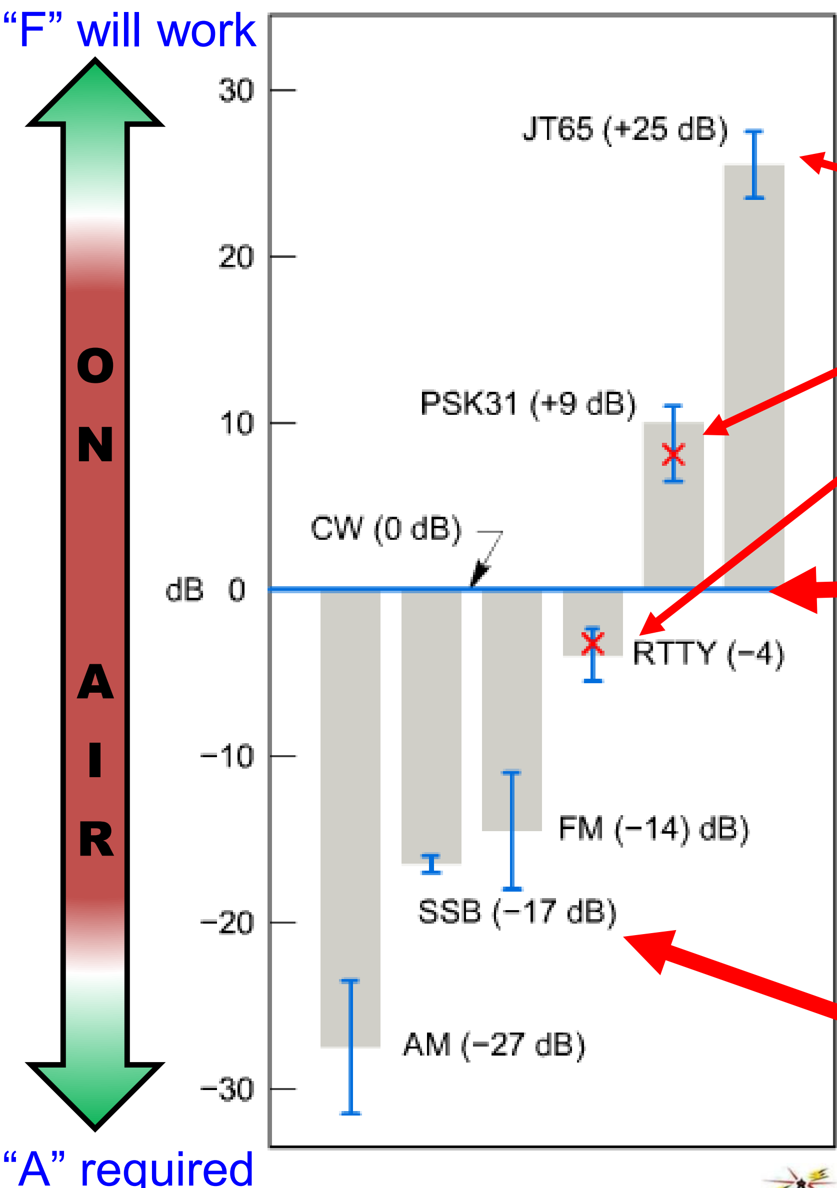
Villages Antenna Guide

The Villages Amateur RADIO Club K4VRC

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D
Screwdriver	B	B	None	C	D	B	B	B	B	B	B	B	D	D	D
Fishing Pole	B	C	Remote	D	C	C	B	B	B	B	A	A	C	D	D
Trapped Vertical	C	C	Shack	D	D	C	C	C	C	C	C	C	C	D	D
Palm Tree Cage	B	A	Remote	F	F	C	B	B	B	B	A	A	A	A	B
Rain Downspout	D	A	Remote	C	C	D	C	C	D	D	D	D	D	F	F
Antenna	**On Air**	**Stealth**	**Tuner**	**Install**	**Cost**	**6M**	**10M**	**12M**	**15M**	**17M**	**20M**	**30M**	**40M**	**80M**	**160M**
Dipole	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Inverted Vee	C	D	Shack	C	B	C	B	B	B	B	C	C	C	D	F
G5RV Jr	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F
Slinky Dipole	D	C	Shack	B	B	C	C	C	C	D	D	F	F	F	F
Helical-Coil Dipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F
Wound Vert Dipole	C	D	Shack	B	C	B	B	C	C	C	D	D	F	F	F
Fence Dipole	D	A	Remote	C	C	F	F	D	D	D	D	C	C	C	B
TAK-tenna	D	B	Shack	B	C	C	C	C	C	C	C	D	D	F	F
Antenna	**On Air**	**Stealth**	**Tuner**	**Install**	**Cost**	**6M**	**10M**	**12M**	**15M**	**17M**	**20M**	**30M**	**40M**	**80M**	**160M**
Off Center Fed	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Windom	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Inverted L	A	B	Remote	C	C	B	B	A	A	A	A	A	A	A	A
End Fed	B	B	Remote	B	C	B	B	B	B	B	B	C	C	F	F
Random Wire	C	B	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Flagpole L	A	B	Remote	C	F	B	B	A	A	A	A	A	A	A	A
Rain Gutter Dipole	D	A	Shack	C	C	F	F	D	D	C	C	C	D	D	D
Spiral Dipole	D	B	Shack	B	C	C	C	C	C	C	C	D	D	F	F
Antenna	**On Air**	**Stealth**	**Tuner**	**Install**	**Cost**	**6M**	**10M**	**12M**	**15M**	**17M**	**20M**	**30M**	**40M**	**80M**	**160M**
WL Horz Loop	D	C	Remote	D	D	F	F	D	D	C	C	C	D	D	D
Rain Gutter Loop	D	A	Shack	D	C	F	F	F	D	C	C	D	D	D	F
WL Vert Loop	B	B	Shack	B	B	B	A	B	A	B	A	B	A	C	F
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

"Villages Antenna Guide" is your shopping list

How does my Mode matter to my antenna?



Digital depends on the specific mode

- JT-65 works on almost anything
- PSK-31 works well with a C or D grade
- RTTY requires a B grade for solid copy

CW will be successful with a C or D grade

Ever wonder why antenna ads rarely state modes?

I have your XYZ up for about month and I am busting pile ups everywhere and receiving 59's every time : -)

SSB will require an A or B grade in most cases

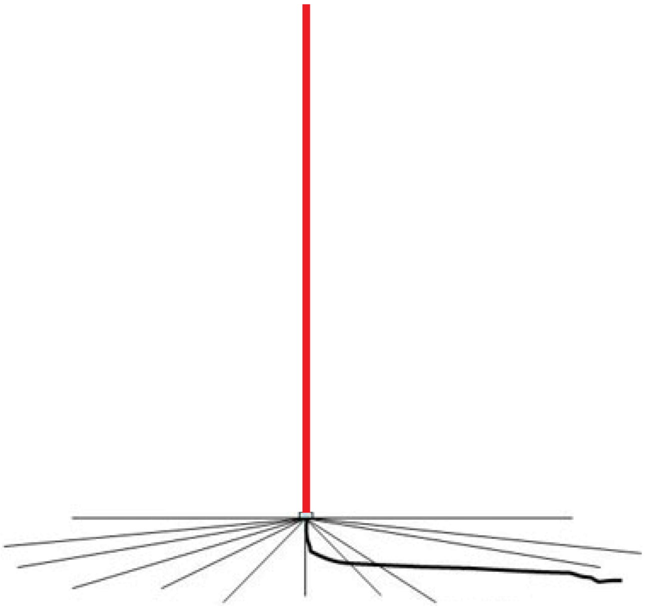
Flagpole

"Shorten" or "Loaded" Monopoles

Flagpoles can easily be used as a 21 Foot Vertical

Planning is important factor in disguising your remote tuner

A minimum of 32 radials for an efficient RF



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

QST, March 2010, P 30-33

Flagpole

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

Before we start what does the summary antenna chart mean?

Factors are graded A best to F least, just like school

- **On Air** is the average RF Radiation Efficiency for 40M – 10M (most people)
- **Each band** is graded based on the radiating element size, height vs WL

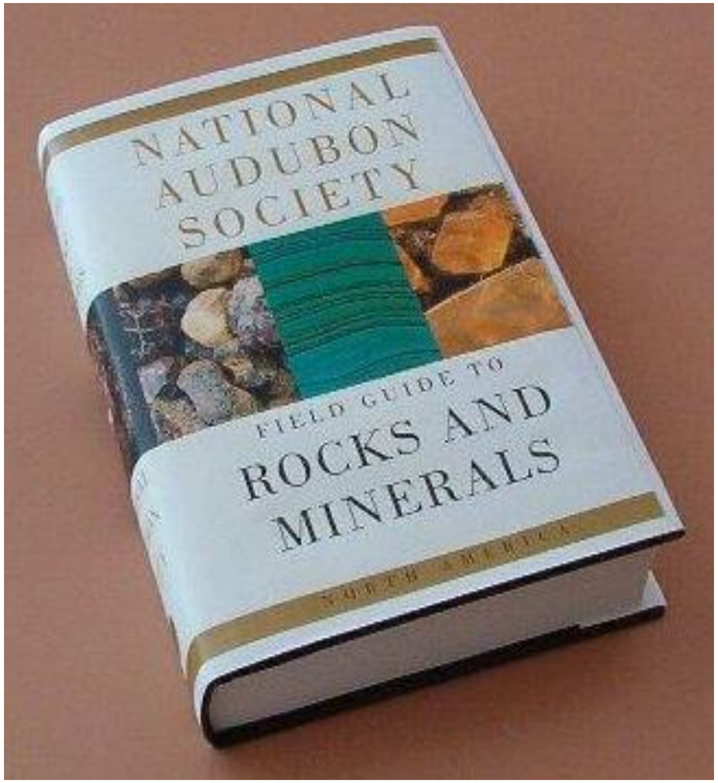
  Each person can decide which bands are important to them
- **Stealth** is graded on how invisible or non-antenna like the appearance
- **Tuner** is the tuner location that drives the cost, site plan and landscaping
- **Install** is the how much work is needed; like radials and landscaping
- **Cost** is graded A for least to F most expense;

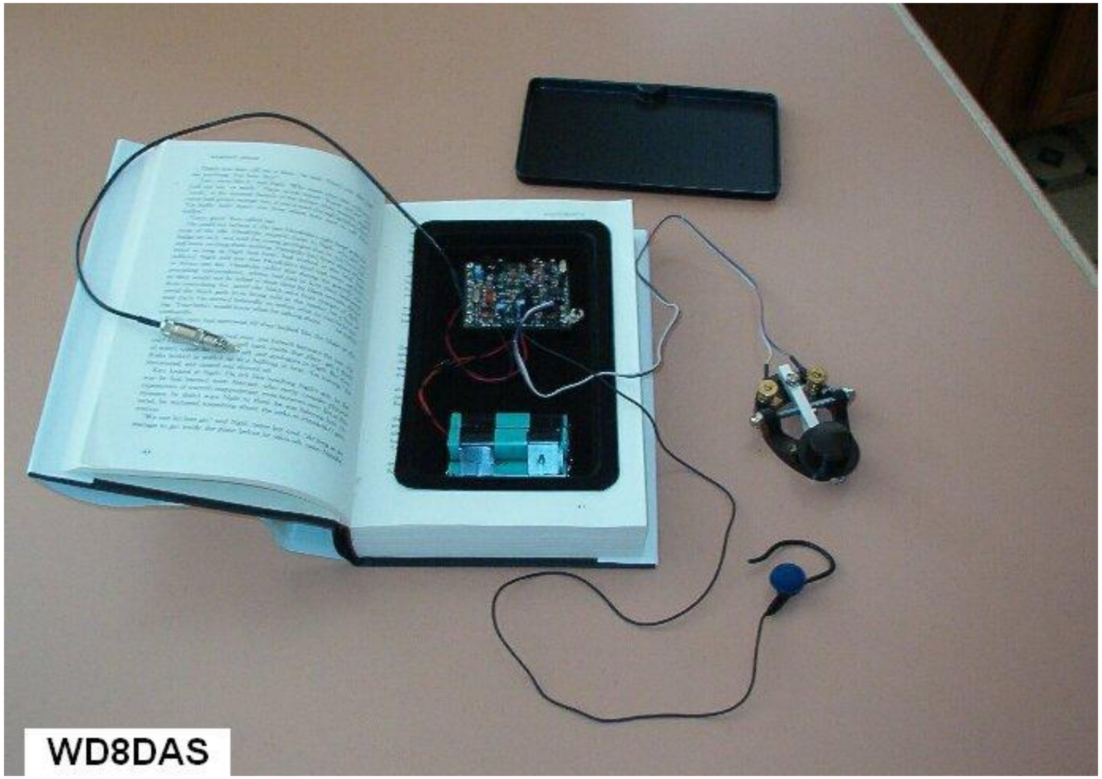
  Example the flagpole gets an "F" for high cost as it requires many costly items
  - Radials $200 - $300
  - Pole & Flag Kit $100 - $200
  - Remote Tuner $300 - $400
  - Underground feed line & protective conduit $?
  - Underground Power for Tuner $?
  - Landscaping $?
- This is a shopping list, not the DIY which will come in later presentations

Stealth

Stealth comes in two forms;

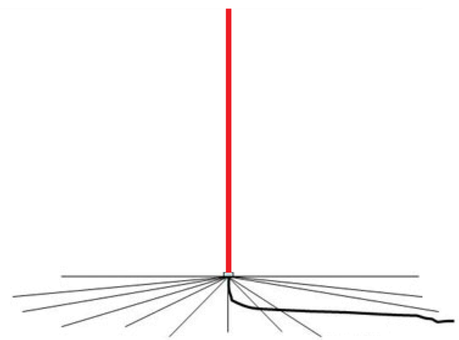
- Hiding in plain sight by looking like a common object (Flagpole)
- Hiding in by being almost invisible (#28 AWG wire)





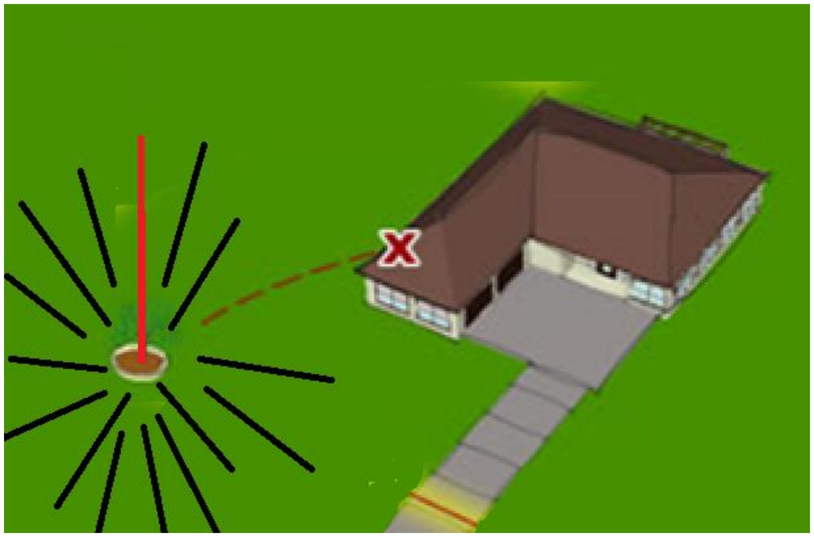
Flagpole

"Shorten" or "Loaded" Monopoles



Be sure to do a site plan

- Radial Placement
- Feed line runs
- Concealing your tuner
- Access for maintenance
- Power for remote tuner
- Power for landscape lighting



PRO
- **Stealth**
- **On Air**

CON
- **Cost**
- **Install**

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

PRO
- Stealth
- On Air

Flagpole

“Shorten” or “Loaded” Monopoles

CON
- Cost
- Install

The installation needs to look like a Flagpole

Today’s neighbors don’t care next year brings a different answer

The best rule is not to look like an antenna

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

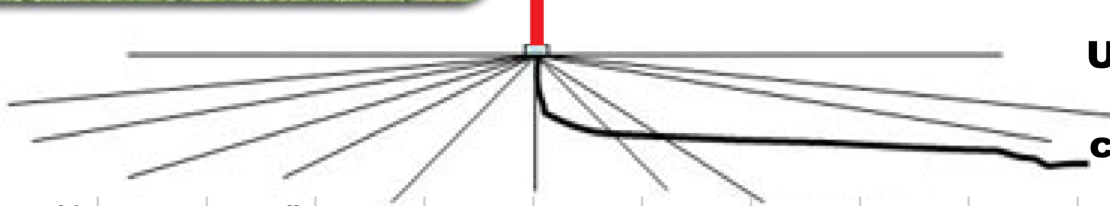
PRO
- Stealth
- On Air

Flagpole

“Shorten” or “Loaded” Monopoles

CON
- Cost
- Install

A minimum of 32 radials for an efficient RF is step one



Invisible Dog Fence installers charge $200 -$300

Using an edger and hand installation costs only the wire

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

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PRO
- **Stealth**
- **On Air**

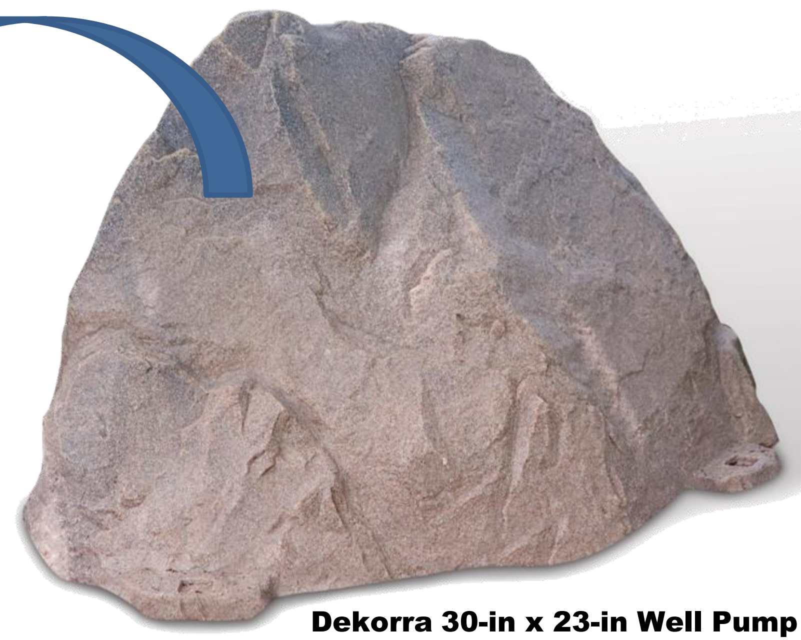
Flagpole

“Shorten” or “Loaded” Monopoles

CON
- **Cost**
- **Install**

One of the best ideas for disguising your remote tuner is a fiberglass water well pump cover

Keeps electronics hidden, dry and accessible later



Dekorra 30-in x 23-in Well Pump Cover
Lowes Item #: 307793 $54.98

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

PRO
- Stealth
- On Air

Flagpole

"Shorten" or "Loaded" Monopoles

CON
- Cost
- Install

Depending on the size and shape of your base equipment the disguise your can be made from plastic privacy fencing components

Keeps electronics hidden, dry and accessible later

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

PRO

- Stealth
- On Air

Flagpole

“Shorten” or “Loaded” Monopoles

CON

- Cost
- Install

Testing before digging is a great planning tool

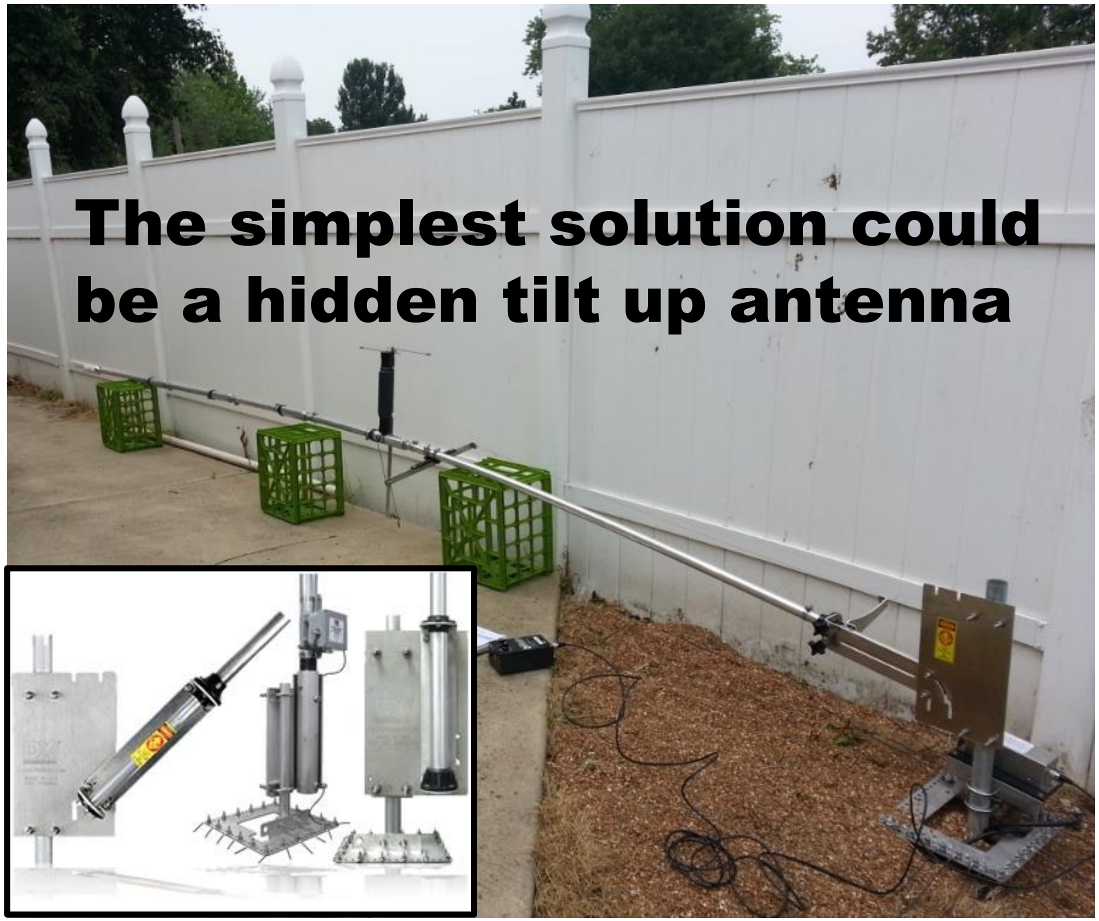
A tripod with a fishing pole will give you on air performance

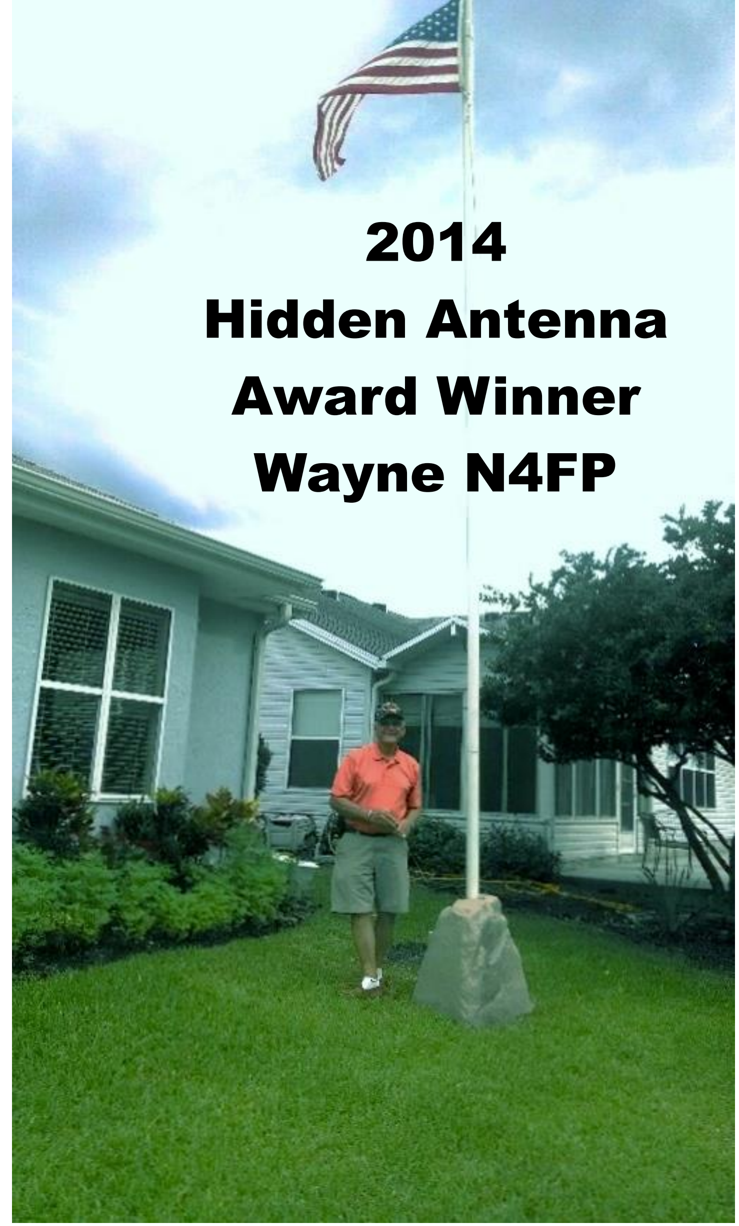
Experimenting with radials before digging has advantages

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

Flagpole

“Shorten” or “Loaded” Monopoles





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D

Before the next antenna

Now that the summary chart and planning considerations for any antenna has been explained the rest of the presentation will be antenna descriptions with any special considerations.

Villages Antenna Guide

The Villages FLORIDA Amateur RADIO Club K4VRC

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole	B	A	Remote	D	F	C	B	B	B	B	A	A	C	D	D
Screwdriver	B	B	None	C	D	B	B	B	B	B	B	B	D	D	D
Fishing Pole	B	C	Remote	D	C	C	B	B	B	B	A	A	C	D	D
Trapped Vertical	C	C	Shack	D	D	C	C	C	C	C	C	C	C	D	D
Palm Tree Cage	B	A	Remote	F	F	C	B	B	B	B	A	A	A	A	B
Rain Downspout	D	A	Remote	C	C	D	C	C	D	D	D	D	D	F	F
Antenna	**On Air**	**Stealth**	**Tuner**	**Install**	**Cost**	**6M**	**10M**	**12M**	**15M**	**17M**	**20M**	**30M**	**40M**	**80M**	**160M**
Dipole	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Inverted Vee	C	D	Shack	C	B	C	B	B	B	B	C	C	C	D	F
G5RV Jr	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F
Slinky Dipole	D	C	Shack	B	B	C	C	C	C	D	D	F	F	F	F
Helical-Coil Dipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F
Wound Vert Dipole	C	D	Shack	B	C	B	B	C	C	C	D	D	F	F	F
Fence Dipole	D	A	Remote	C	C	F	F	D	D	D	D	C	C	C	B
TAK-tenna	D	B	Shack	B	C	C	C	C	C	C	C	D	D	F	F
Antenna	**On Air**	**Stealth**	**Tuner**	**Install**	**Cost**	**6M**	**10M**	**12M**	**15M**	**17M**	**20M**	**30M**	**40M**	**80M**	**160M**
Off Center Fed	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Windom	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Inverted L	A	B	Remote	C	C	B	B	A	A	A	A	A	A	A	A
End Fed	B	B	Remote	B	C	B	B	B	B	B	B	C	C	F	F
Random Wire	C	B	Shack	B	B	C	C	C	C	C	C	D	D	F	F
Flagpole L	A	B	Remote	C	F	B	B	A	A	A	A	A	A	A	A
Rain Gutter Dipole	D	A	Shack	C	C	F	F	D	D	C	C	C	D	D	D
Spiral Dipole	D	B	Shack	B	C	C	C	C	C	C	C	D	D	F	F
Antenna	**On Air**	**Stealth**	**Tuner**	**Install**	**Cost**	**6M**	**10M**	**12M**	**15M**	**17M**	**20M**	**30M**	**40M**	**80M**	**160M**
WL Horz Loop	D	C	Remote	D	D	F	F	D	D	C	C	C	D	D	D
Rain Gutter Loop	D	A	Shack	D	C	F	F	F	D	C	C	D	D	D	F
WL Vert Loop	B	B	Shack	B	B	B	A	B	A	B	A	B	A	C	F
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

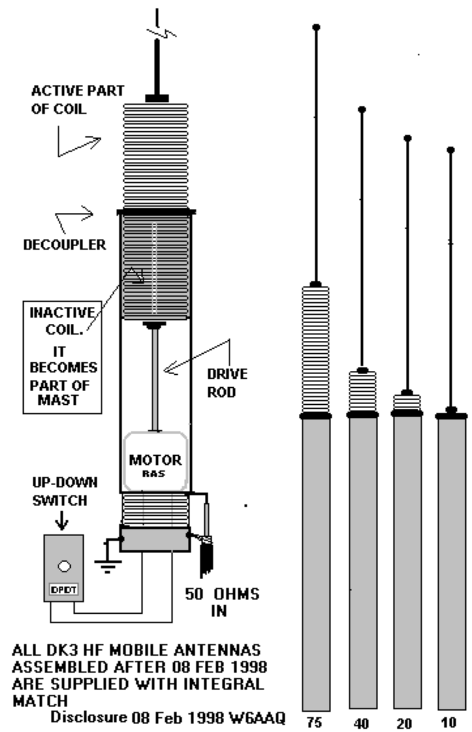
PRO
- **Built-In Tuning**

Screwdriver

CON
- **10 KHz BW**

“Shorten” or “Loaded” Monopoles

Base loaded vertical normally used as mobile antennas. The small size gives stealth, you may “plant” a screwdriver in the garden without drawing attention to it. Adding band extensions to increase performance and use as many ground radials as possible.

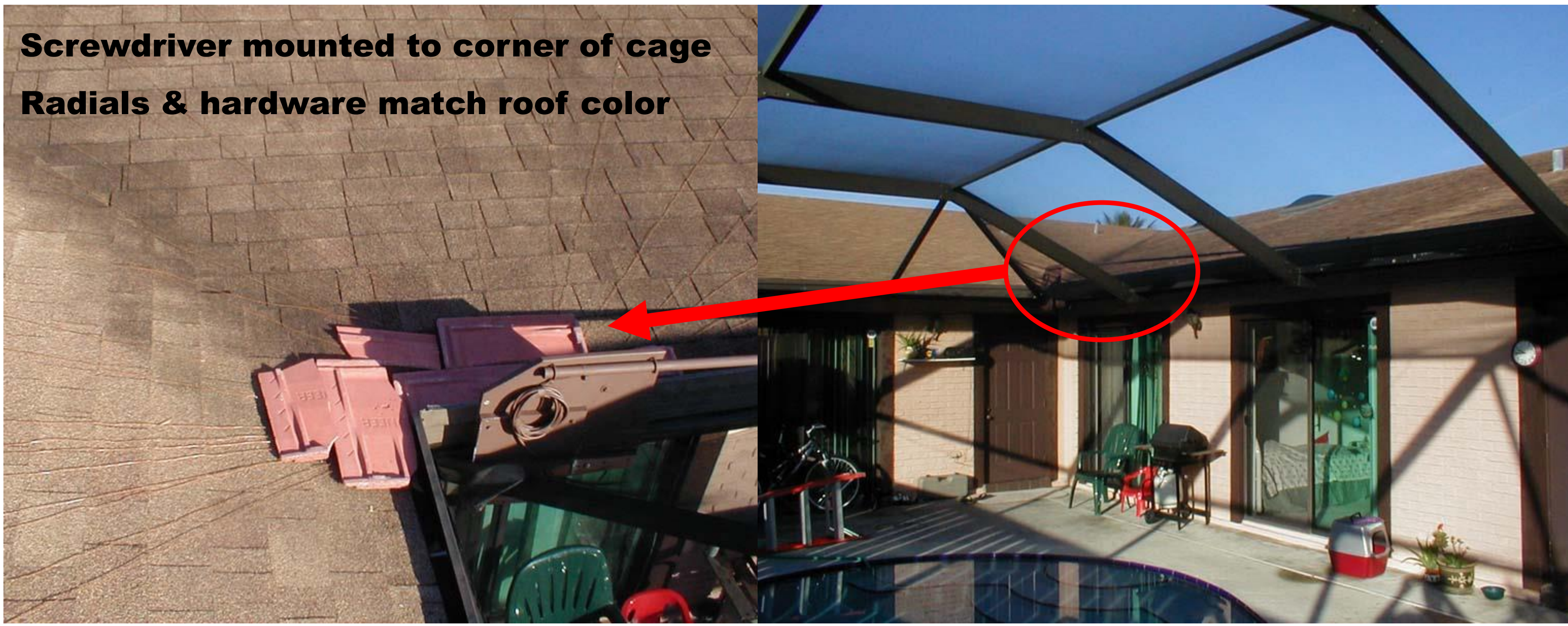


Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Screwdriver	B	B	None	C	D	B	B	B	B	B	B	B	D	D	D

More Screw Driver

“Shorten” or “Loaded” Monopoles

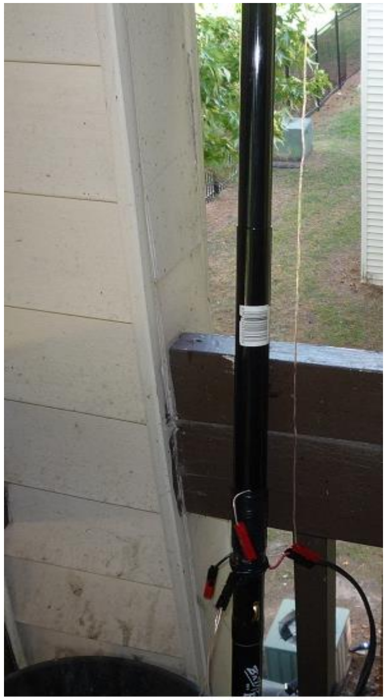
Antenna mounted at inside corner of screen cage to obscure view then painted to match cage frame and roof



Fishing Pole

"Shorten" or "Loaded" Monopoles

This is just a simple 20 foot crappie pole propped up against fence or any object disguise your antenna.

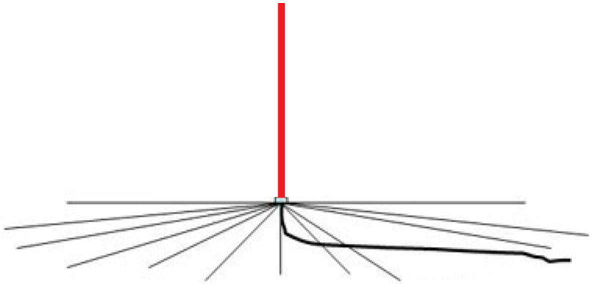


PRO

- **More stealth on patio**

CON

- **Where to put Radials**



Surround the bottom of the pole with an old fishing tackle box to provide your antenna with visual effect

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Fishing Pole	B	C	Remote	D	C	C	B	B	B	B	A	A	C	D	D

more Fishing Pole

"Shorten" or "Loaded" Monopoles

Many options for stealth

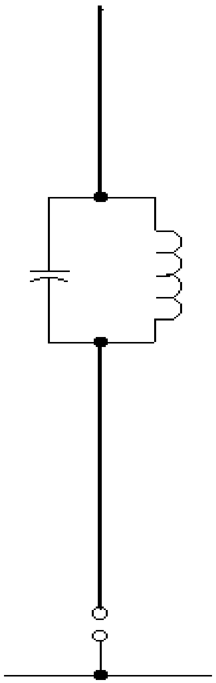
- Tilt up
- Tripod
- PVC Poles
- Clamp to railing

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Fishing Pole	B	C	Remote	D	C	C	B	B	B	B	A	A	C	D	D

Trapped Vertical Antennas

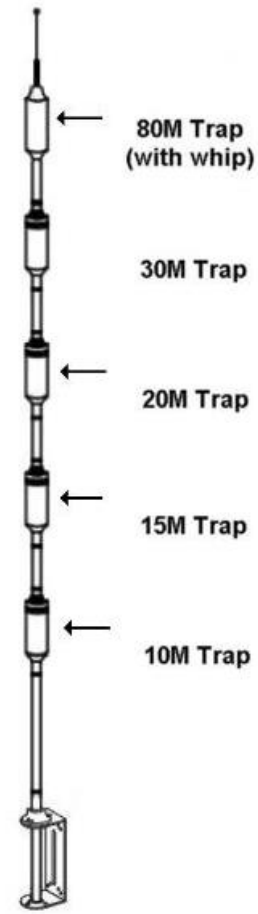
PRO

- **Wide VSWR BW**



“Shorten” or “Loaded” Monopoles

The HF6V antennas are easy to erect and tune antennas that will last you for many years. Butternut HF6V antennas work six bands--80, 40, 30, 20, 15, and 10 meters--with an extremely efficient vertical radiator that's only 26 ft. tall!



The traps are low pass filters that make the antenna electrically shorter as frequency increases to maintain a lower VSWR but reduces On Air performance

CON

- **On Air**

Tapped verticals are often hidden inside PVC Flagpole for stealth

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Trapped Vertical	C	C	Shack	D	D	C	C	C	C	C	C	C	C	D	D

more Trapped Vertical Antennas

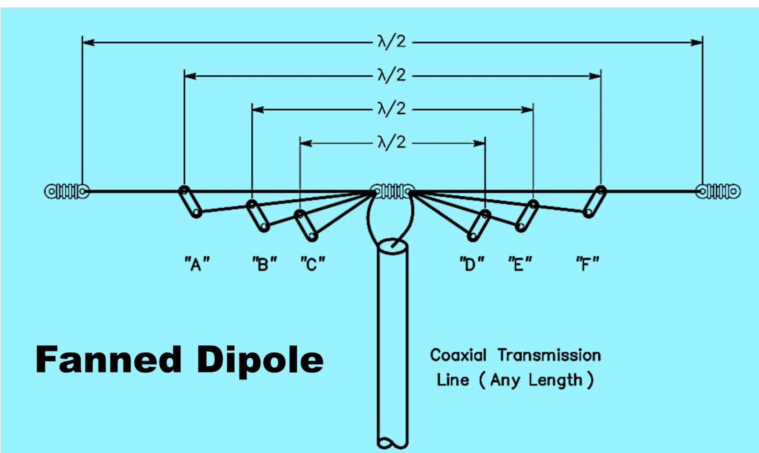
"Shorten" or "Loaded" Monopoles

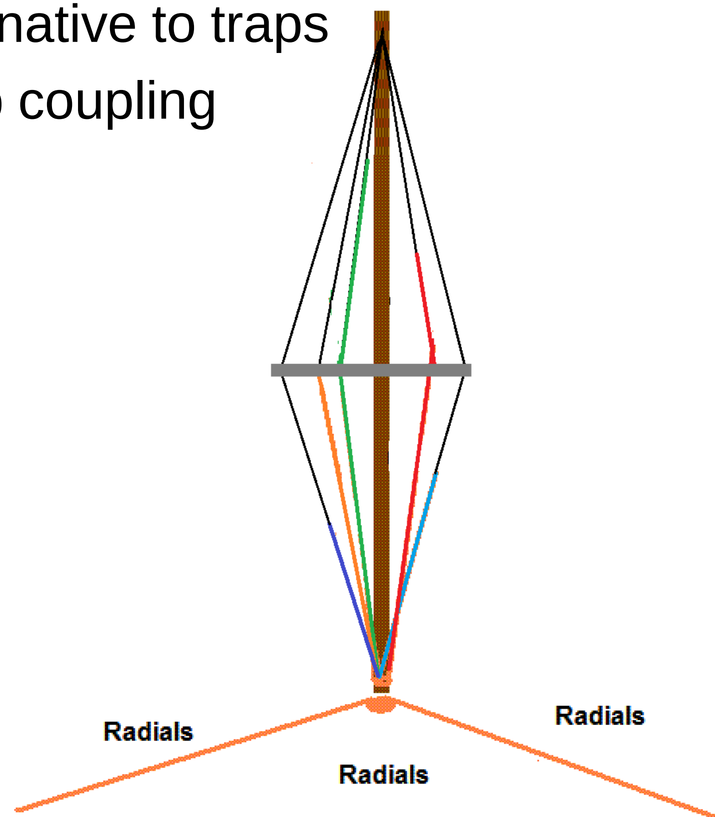
Traps lower efficiency on lower frequencies

Separate elements are an alternative to traps

Elements are separated to stop coupling

Works like a "Fanned Dipole"





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Trapped Vertical	C	C	Shack	D	D	C	C	C	C	C	C	C	C	D	D

Palm Tree Caged

Monopole with Radials

- Palms can be 30 to 40 Feet and do better on 80M & 160M than Flagpoles limited to 21 Feet
- Disguising your remote tuner in plain sight as electrical equipment for your lights
- Radiating element can be Xmas lights or Gray-Brown wire to form a "*Caged*" radiating element
- Still need many radials for an efficient RF

PRO
- **Stealth**
- **On Air**

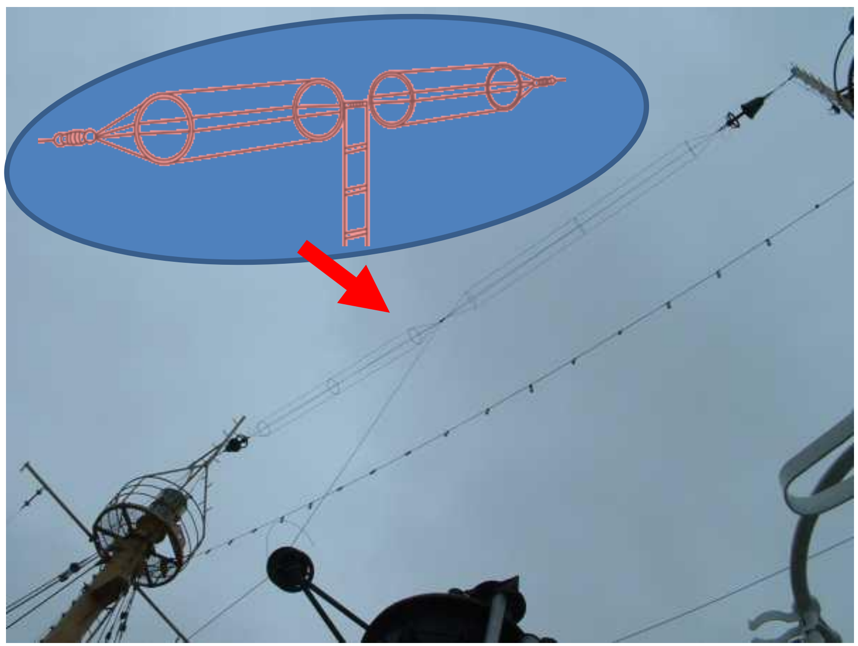
CON
- **Cost**
- **Install**

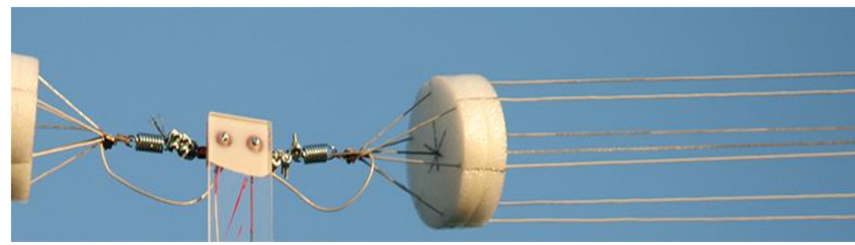
Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Palm Tree Cage	B	A	Remote	F	F	C	B	B	B	B	A	A	A	A	B

what is **Caged**

Monopole with Radials

A “cage” antenna is electrically a cylindrical conductor that appears electrically as a much larger and longer single conductor providing greater bandwidth / SWR. It can be shorter physically and was often used on ships with limited distance between masts for HF into the 1960s. The use of higher frequencies and availability better tuners resulted in the cage fading away.





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Palm Tree Cage	B	A	Remote	F	F	C	B	B	B	B	A	A	A	A	B

PRO
- **Stealth**

Rain Downspout

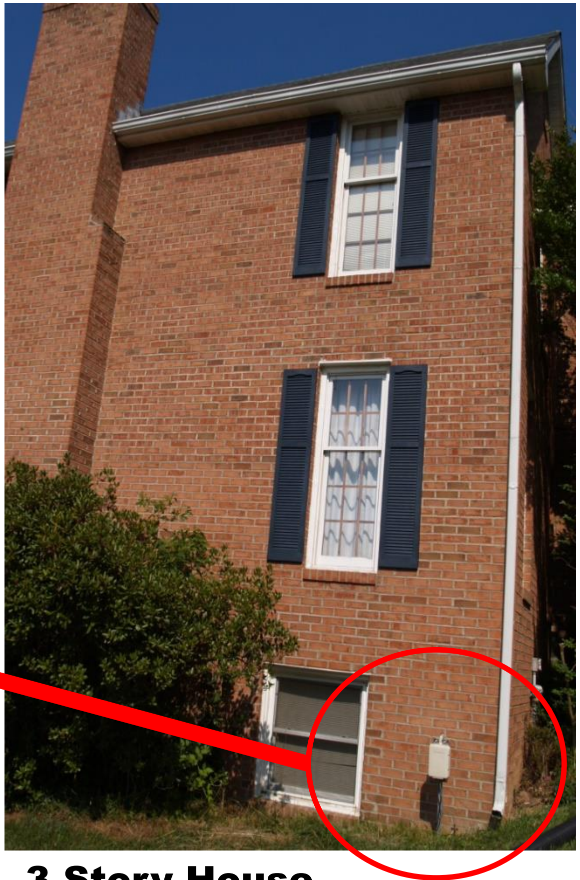
"Shorten" or "Loaded" Monopoles

CON
- **On Air**
- **Install**

Rain downspout antenna is a difficult install job
- The gutter and downspout are isolated from ground
- Electrical continuity between sections of your downspout is a maintenance problem
- Coupling to the house, aluminum window and screen cages detunes
- Success has been at 2 or 3 story homes

Poor Conductivity

Remote Tuner



3 Story House

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Rain Downspoot	D	A	Remote	C	C	D	C	C	D	D	D	D	D	F	F

Before the next antenna

Newer homes are being made with aluminum roof sheathing. Basically plywood or OSB sheathing with a thin aluminum facing on one side as a radiant heat barrier. The **aluminum blocks RF** and precludes many of the attic antenna installations for homes south of 466.

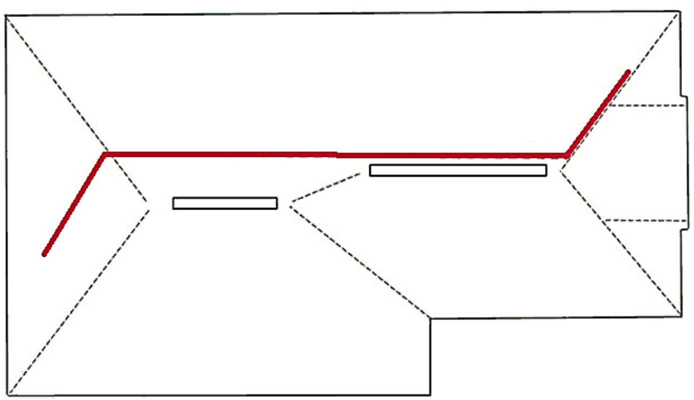
PRO
- Cost

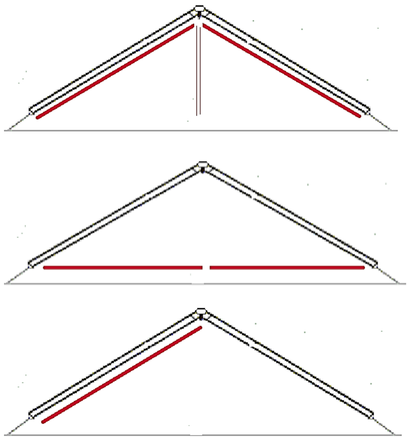
Dipole

Center-Fed-Dipoles - ½ Wavelength

CON
- NVIS
- On Air

- ½ WL dipole oriented horizontal and center fed
- Resonate 40M and 15M is ~ 65 Feet Long
- May take many shapes to fit in attic space
- 2.16 dBi perpendicular in free space
- NVIS at ten feet above ground drop to -9 dBi
- Attic is most common installation



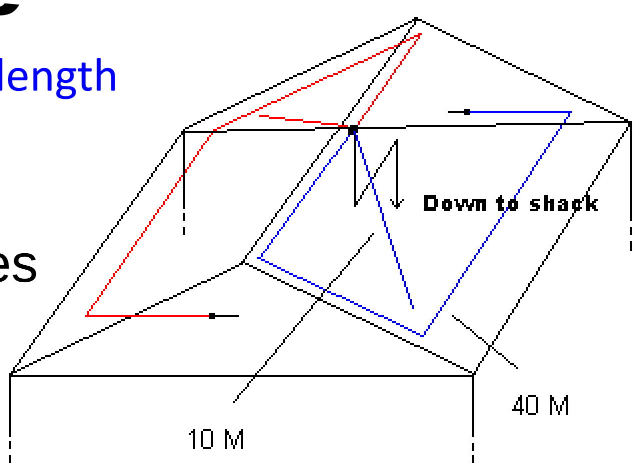


Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Dipole	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

More Dipole

Center-Fed-Dipoles - ½ Wavelength

- Color is key to stealth
- Location can be under soffits or over shingles
- Straight lines are not required
- Multi-antennas required for matching
- Primary & Odd Multiples are resonant



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Dipole	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

PRO
- Cost

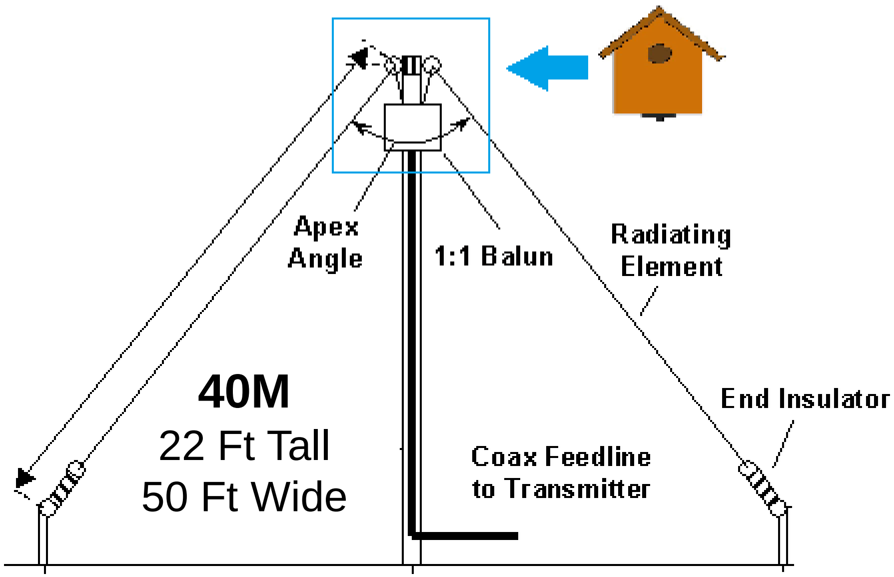
Inverted Vee

CON
- Stealth

Center-Fed-Dipoles - ½ Wavelength

"Birdhouse Antenna"

- Elements "support" the birdhouse pole
- Birdhouse covers feed point & coax in PVC pipe
- Tell everyone how much you love bird watching!
- Less NVIS than attic or roof Dipole



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Inverted Vee	C	D	Shack	C	B	C	B	B	B	B	C	C	C	D	F

G5RV Jr

PRO
- Cost

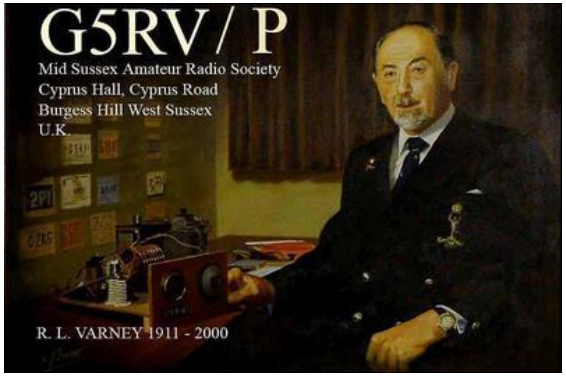
CON
- On Air
- Install

Center-Fed-Dipoles - ½ Wavelength

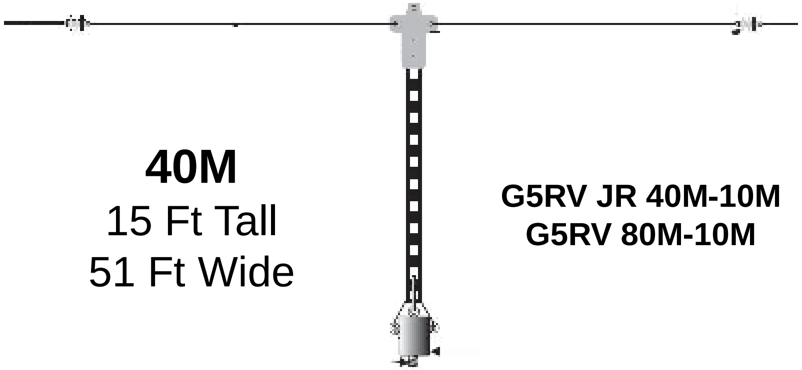
G5RV popular multi-band "compromise" antenna

Ladder Line must be in free space and vertical

Demands better tuner than dipole or OCF



Invented in 1946 by Louis Varney, G5RV (SK)



40M
15 Ft Tall
51 Ft Wide

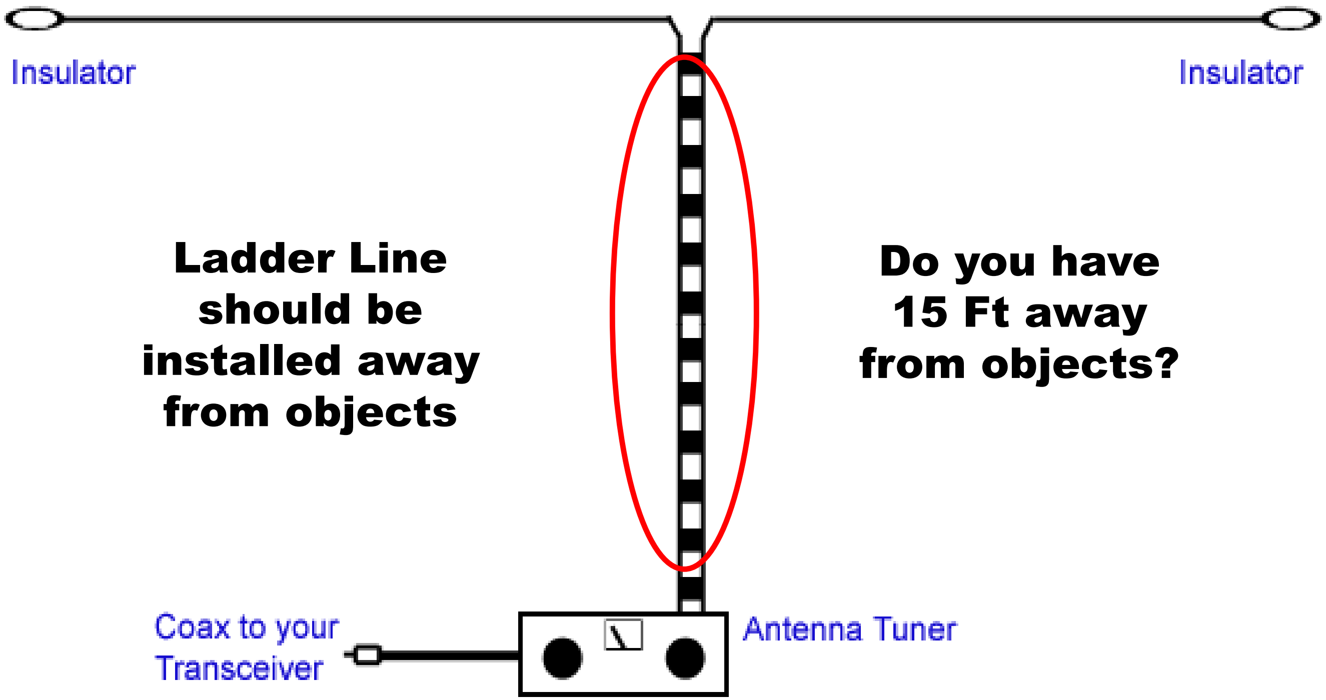
G5RV JR 40M-10M
G5RV 80M-10M

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
G5RV Jr	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

G5RV Jr

Center-Fed-Dipoles - ½ Wavelength

Issue - Ladder Line must be in free space



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
G5RV Jr	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

G5RV Jr

Center-Fed-Dipoles - ½ Wavelength

Issue - Ladder Line must be in free space

Ladder Line should be installed away from objects

G5RV intended for Free Space

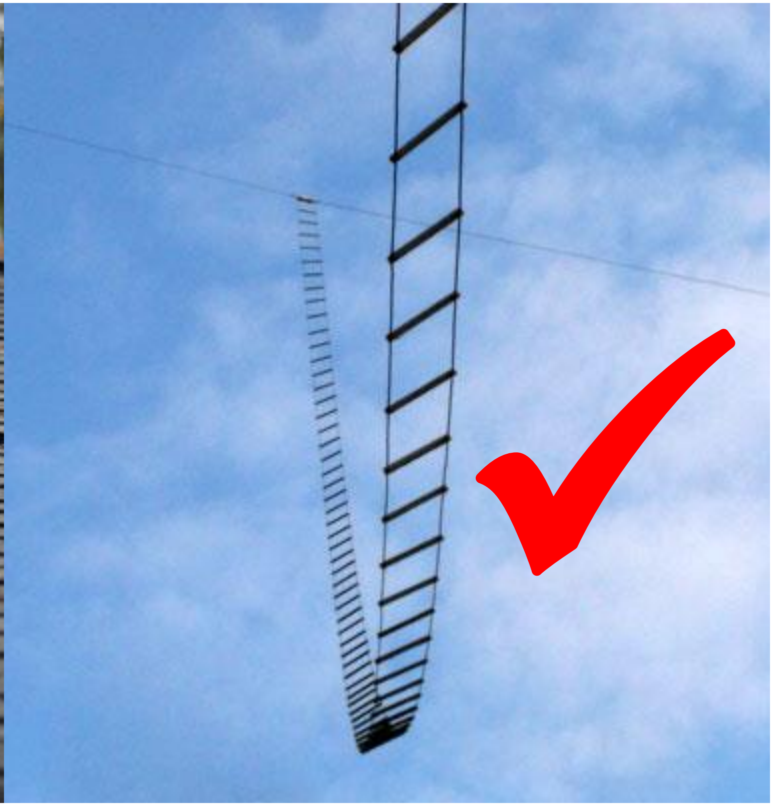
Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
G5RV Jr	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

G5RV Jr

Center-Fed-Dipoles - ½ Wavelength

Issue - Ladder Line must be in free space

Ladder Line should be installed away from objects



G5RV intended for Free Space

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
G5RV Jr	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

PRO
- Backpack
- Portable

Buddipole

CON
- On Air
- Cost

Center-Fed-Dipoles -"Loaded" Dipole

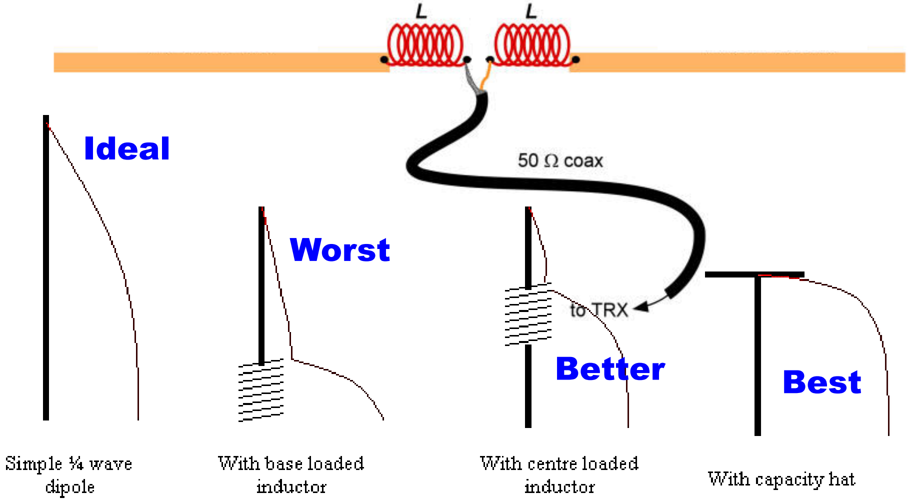
Two short elements on a tripod

Tuned by base loaded elements

40M-6M & 2M by changing coils

16 Ft Wide X 10 Ft Tall

~ $500 as shown



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

PRO
- Cost

Slinky Dipole

CON
- On Air

Center-Fed-Dipoles -“Loaded” Dipole

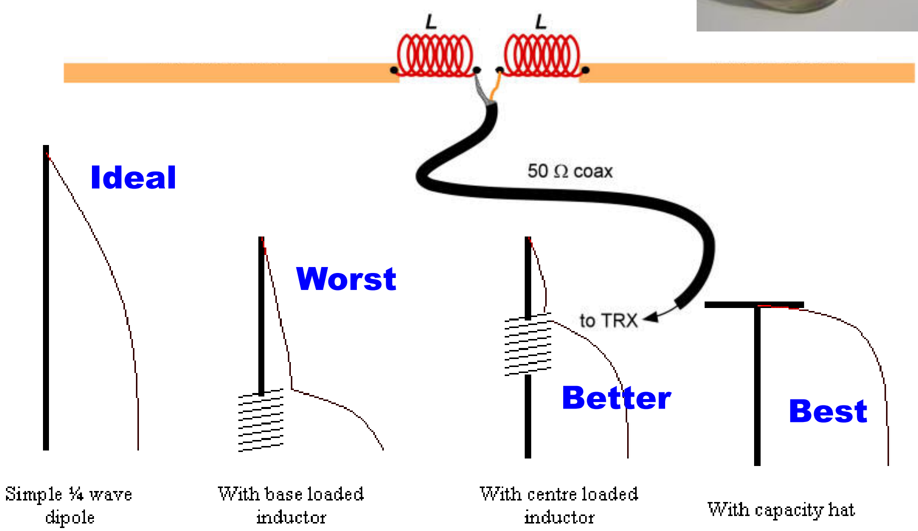
Two shorter loaded elements

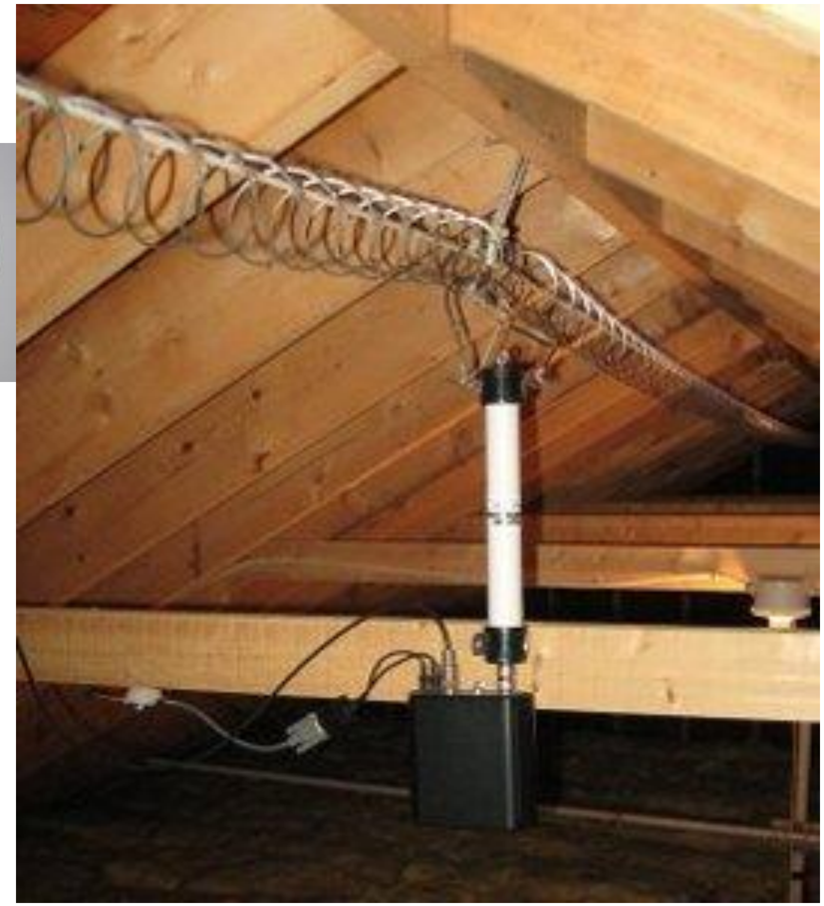
Tuned by stretching (var. Inductor)

40M-10M with tuner

Size to fit space available

Acts like a base load





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

Helical-Coil Dipole

PRO
- Cost

CON
- On Air

Center-Fed-Dipoles - "Loaded" Dipole

The Dowsers Corner Our COAX Stealth Helical

It's a slinky!

~ Shipping Insur. & Del. Conf. Included ~

From QRP up to 100W on Xmit

10M thru 80M in as little as 15'- 20' of space!*

It's a Real FULL SIZED Helical Dipole (approx. +/- 130') all coiled up!!!

Simple permanent or portable mounting!
Indoors ~OR~ Outdoors

SALE PRICE
$35

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Helical-Coil Dipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

PRO
- Install

Wound Vertical Dipole

CON
- On Air

Center-Fed-Dipoles -“Loaded” Dipole

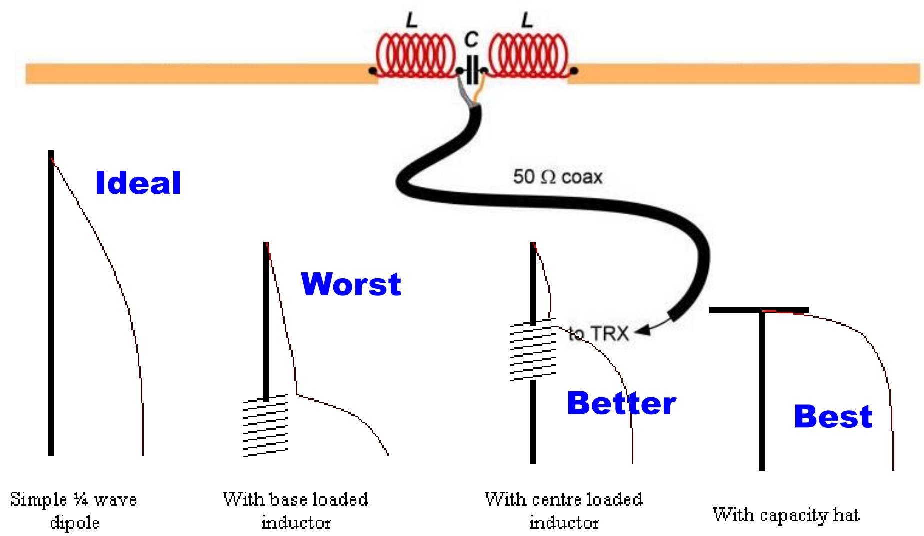
Vertical has less NVIS than Horizontal

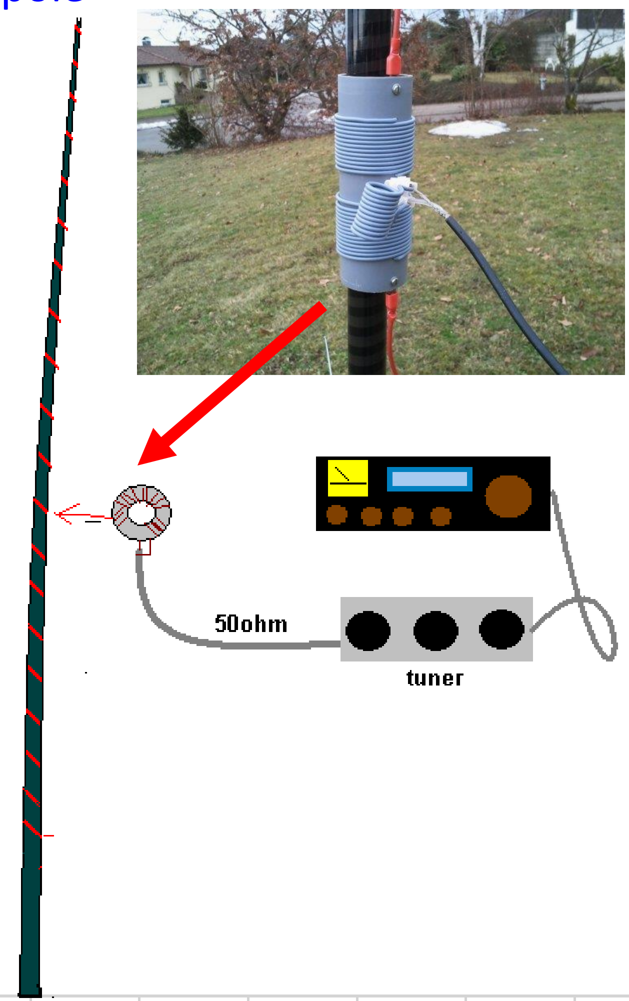
Tuned by adjusting elements

40M-10M, 80M by adding coil

20 Ft Tall wire around a fishing pole

~ $50 as shown





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

PRO
- Backpack
- Portable

Wound Vertical Dipole

Center-Fed-Dipoles -"Loaded" Dipole

CON
- On Air
- Cost

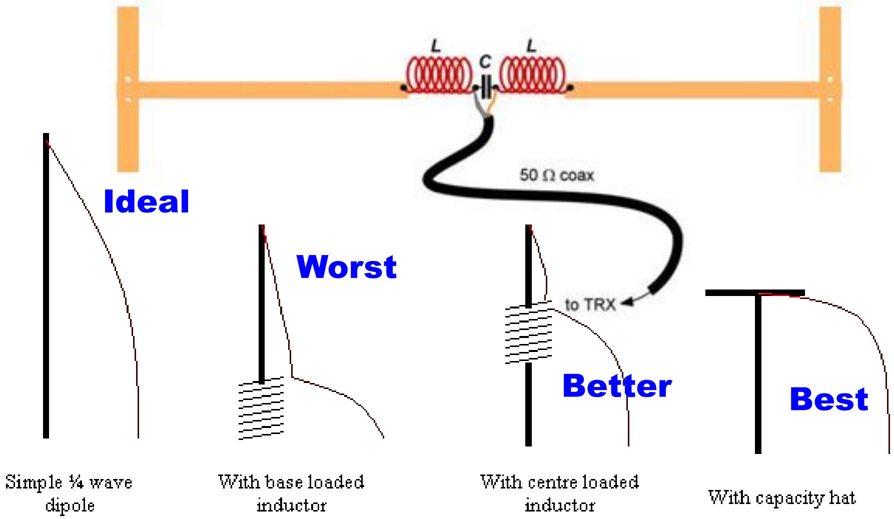
"TransWorld Adventurer"

Tuned by matching network

20M-10M by switching network

5 Ft Wide X 8 Ft Tall

~ $800 as shown



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

PRO
- 160M

Fence Dipole

CON
- On Air

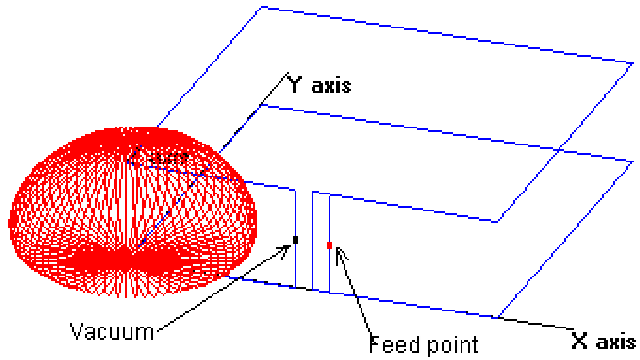
Direct Driven Ring Radiator

Featured in QST as Stealth 80M – 160M

NVIS design

Not for 40M & up

5 Ft High X 62 Ft Long



DDRR and radiation pattern

Figure 1 — Sketch of an 80-meter DDDR-like top-wire loaded vertical monopole mounted on a privacy fence. As noted, it can give a good account of itself, considering its visual impact and cost.

QST® – Devoted entirely to Amateur Radio www.arrl.org **October 2014** **55**

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Fence Dipole	D	A	Remote	C	C	F	F	D	D	D	D	C	C	C	B

PRO
- **Install**

TAK-tenna

CON
- **On Air**

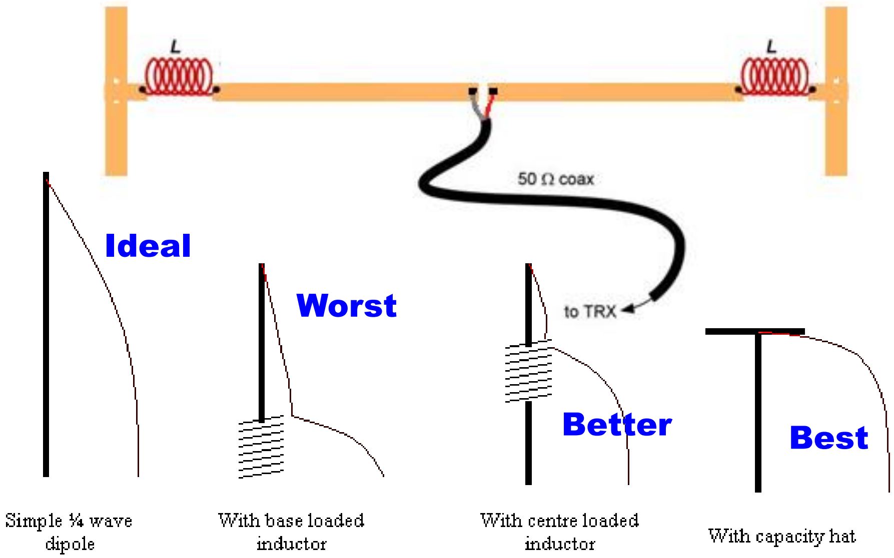
Center-Fed-Dipoles -"Loaded" Dipole

Two short elements with end loads

40M-6M

3 Ft Wide X 3 Ft Tall

~ $180 in Kit Form



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

PRO
- Cost

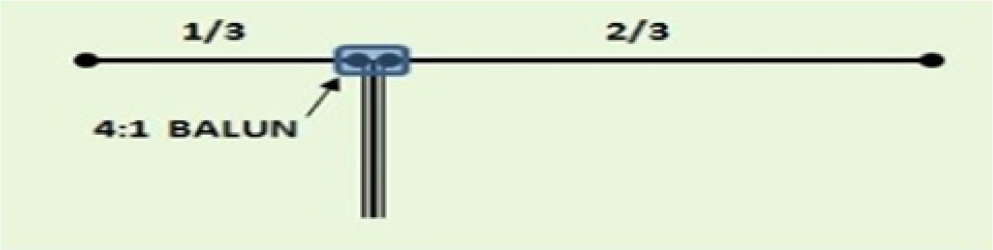
Off-Center-Fed Dipole

CON
- On Air

"Off-Center-Fed" Dipole

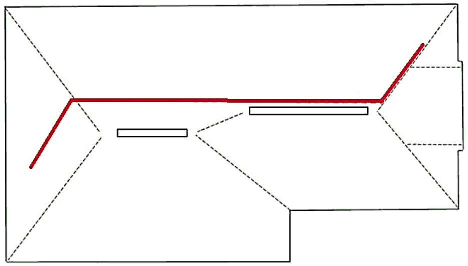
Multi-band "compromise" antenna like G5RV

- No Ladder Line, so easier to install than G5RV
- Easier to match than dipole or OCF for 30M, 17M & 12M
- Resonate 40M, 20M, 15M & 10M ~ 65 Feet Long
- May take many shapes to fit in attic space



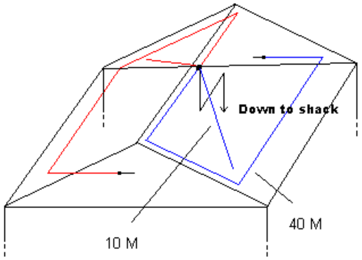
40M
67 Ft Long (1/2 WL)

Line or Zig Zag



On top of shingles

C Shape



In attic

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Off Center Fed	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

PRO
- Cost

OCF DP also called a **Windom Dipole**

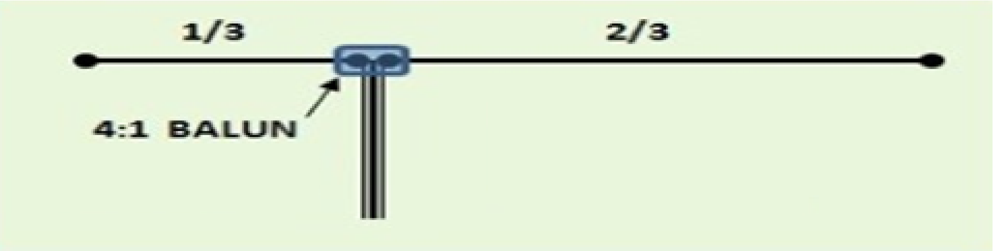
CON
- On Air

"Off-Center-Fed" Dipole

Multi-band "compromise" antenna like G5RV

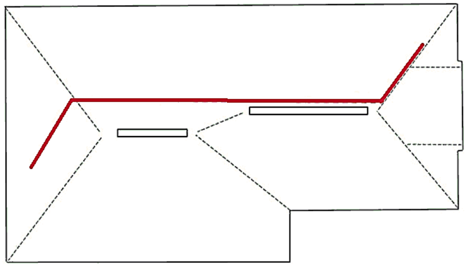
No Ladder Line, so easier to install than G5RV

Easier to match than dipole or OCF



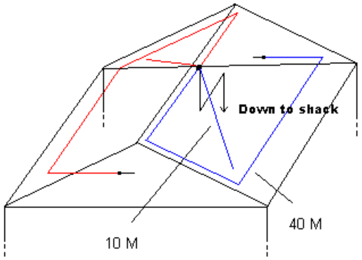
40M
67 Ft Long (1/2 WL)

Line or Zig Zag



On top of shingles

C Shape



In attic

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Off Center Fed	C	C	Shack	B	B	C	C	C	C	C	C	D	D	F	F

Inverted-L

"Vertical" with Radials

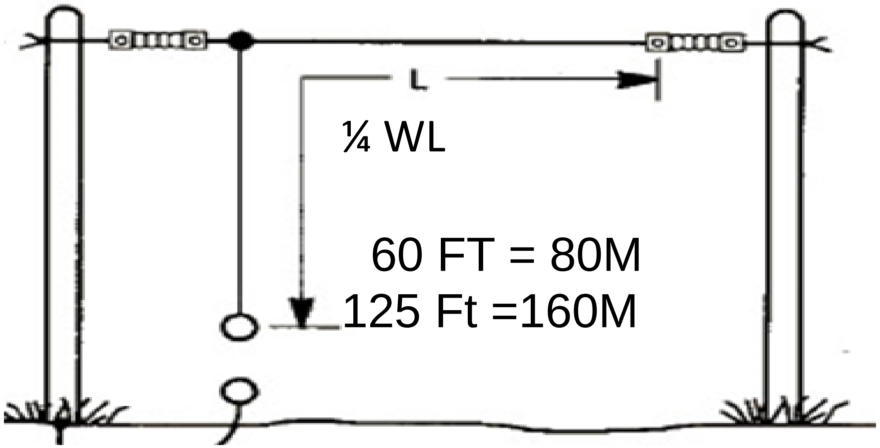
PRO
- **On Air**

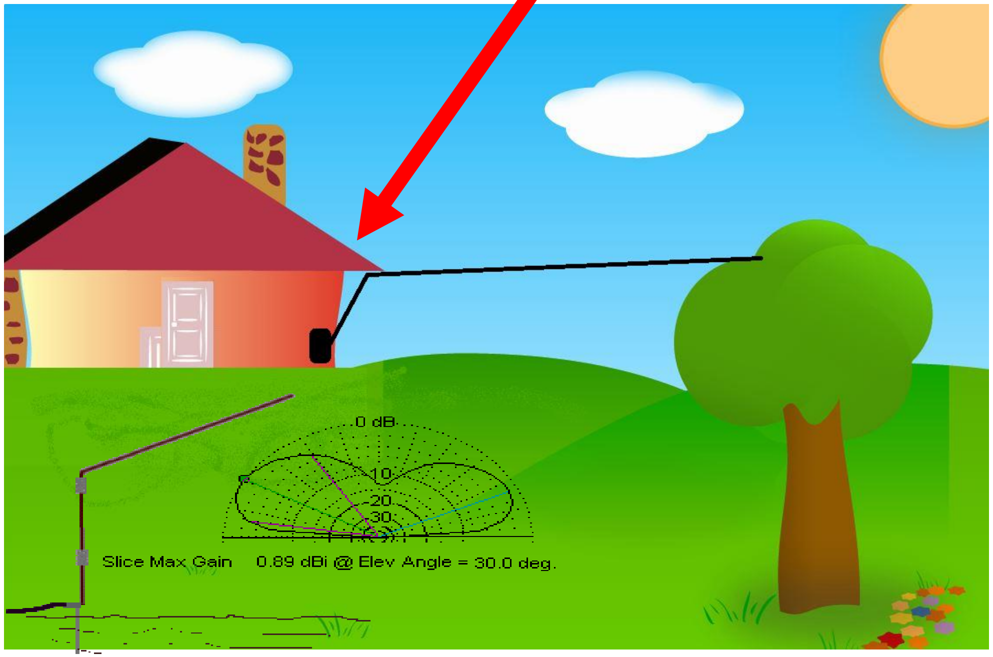
CON
- **None?**
- **You decide!**

Thin wire which is hard to see from a distance

Typically 20 Ft vertical then horizontal to tree

Length determines lowest frequency





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Inverted L	A	B	Remote	C	C	B	B	A	A	A	A	A	A	A	A

PRO

- On

End Fed "Dipole"

"Off-Center-Fed" Dipole

CON

- Length

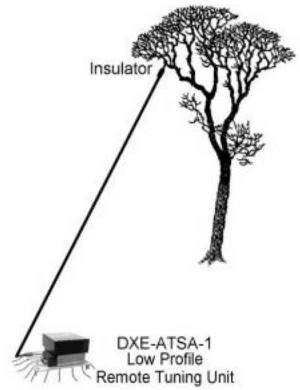
Thin wire which is hard to see fı

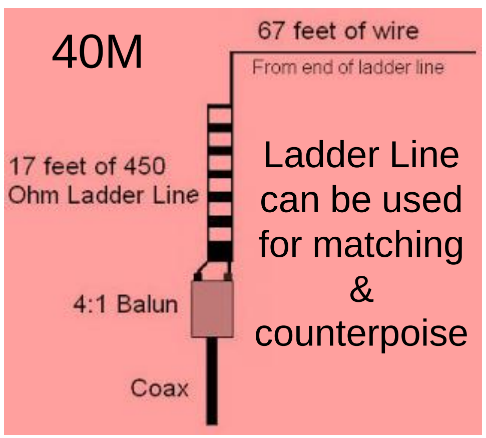
Typically 20 Ft vertical then hori

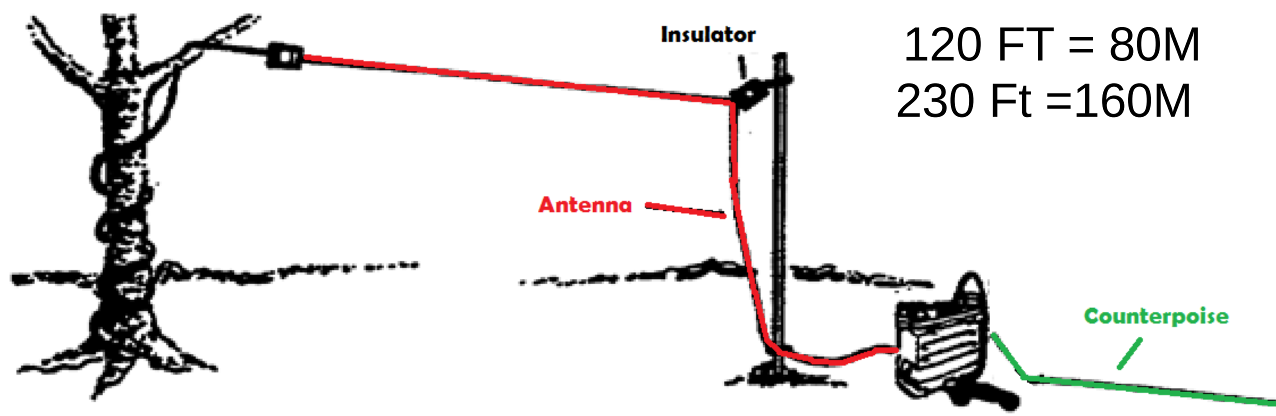
Length determines lowest frequ

Element ~ 92% of ½ WL

Counterpoise ~ 8% of ½ WL







120 FT = 80M
230 Ft =160M

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
End Fed	B	B	Remote	B	C	B	B	B	B	B	B	C	C	F	F

PRO
- On

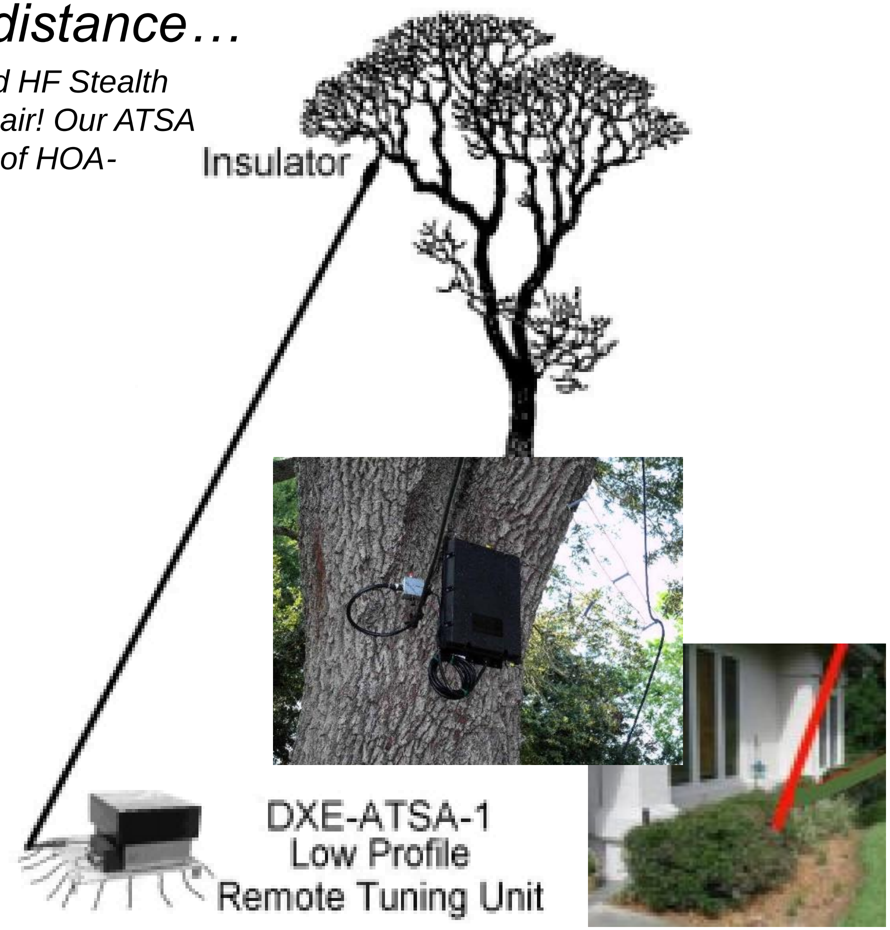
End Fed "Dipole"

CON
- Cost

DX Engineering Auto-Tuned Multi-Band HF Stealth Antenna

"Thin wire which is hard to see from a distance…

… No antennas allowed? DX Engineering Auto-Tuned Multi-Band HF Stealth Antenna Systems help you keep a low profile and still get on the air! Our ATSA concept allows Amateur radio operators living under the shadow of HOA-controlled areas to get on the air easily. "



Antenna	On Air	Stealth	Tuner	Install	~~Cost~~	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
End Fed	B	B	Remote	B	~~C~~	B	B	B	B	B	B	C	C	F	F

PRO
- Cost

Random Wire

“Off-Center-Fed” Dipole

CON
- 40-160M

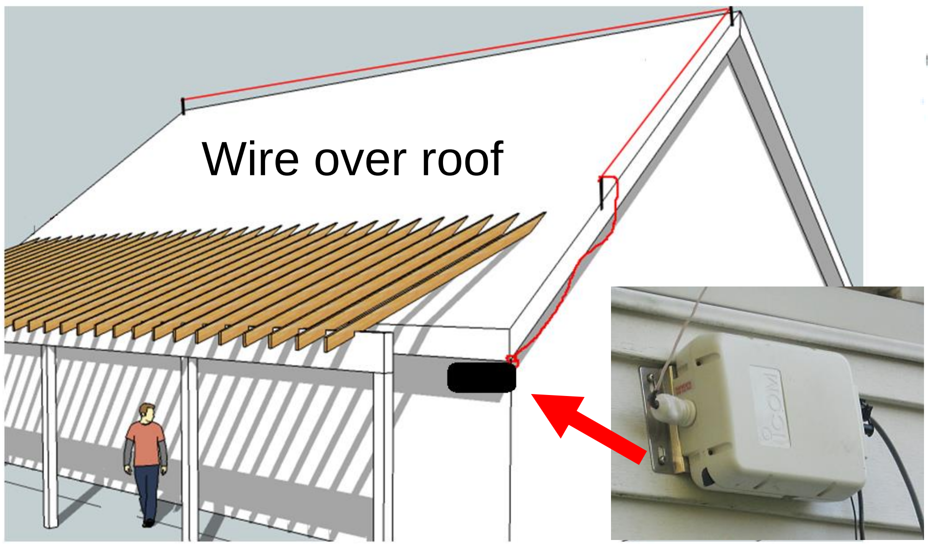
Many recommend lengths published

40M-10M Example = 84' long end fed and a 17' long counterpoise

QST, March 1936, P 32

One solution hide remote tuner & counterpoise under soffit

Random Wire can be run over roof or to tree



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Random Wire	C	B	Shack	B	B	C	C	C	C	C	C	D	D	F	F

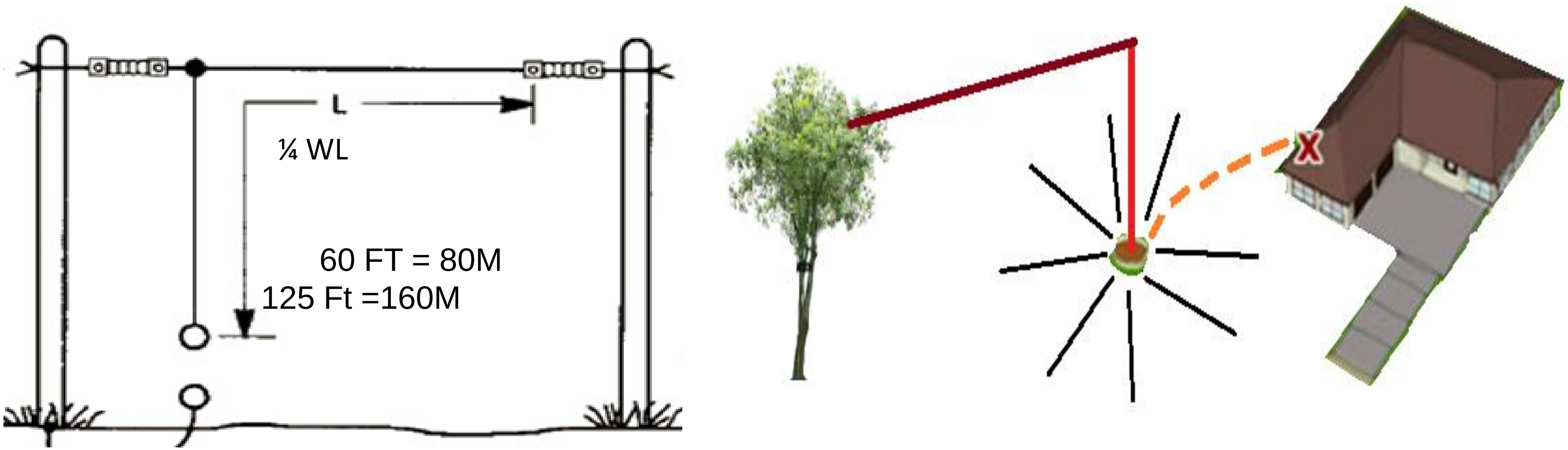
PRO
- On Air

Flagpole-L

"Off-Center-Fed" Dipole

CON
- Cost

Thin wire added to Flagpole
Small wire is hard to see from street
Flagpole for vertical then horizontal to tree
Length determines lowest frequency



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Flagpole L	A	B	Remote	C	F	B	B	A	A	A	A	A	A	A	A

Rain Gutter Dipole

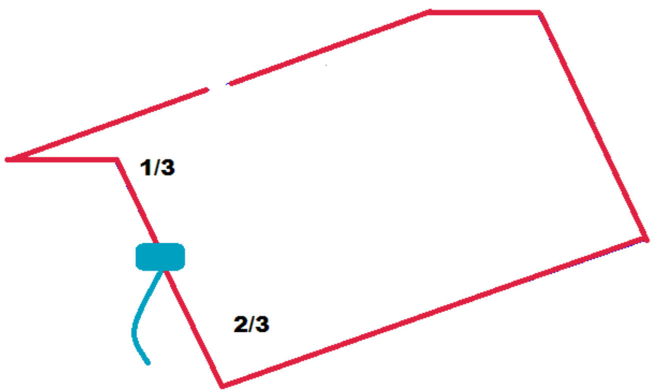
PRO
- **Stealth**

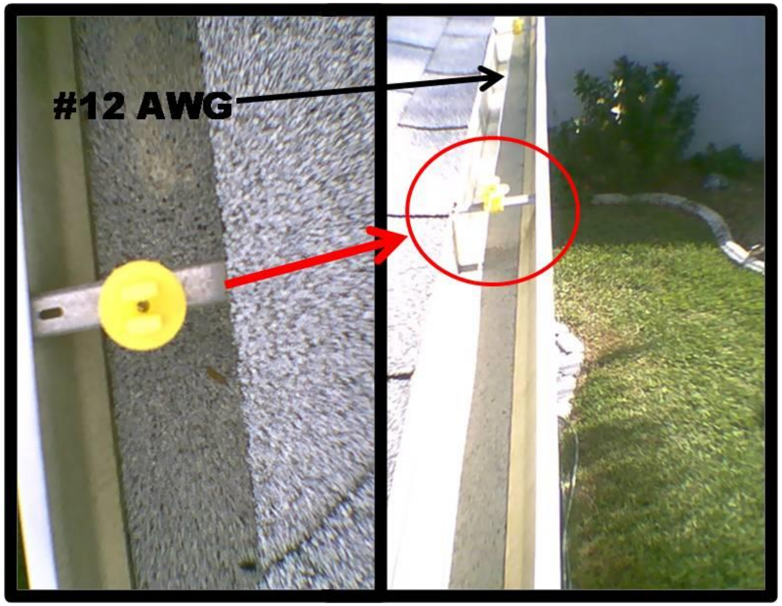
CON
- **On Air**

"Off-Center-Fed" Dipole

Very NVIS Antenna

- Rain Gutter antenna is a difficult install job
- Keep gutters are isolated from ground install wire on insulators
- Electrical continuity between sections is a maintenance problem
- Coupling to the house, aluminum window and screen cages detunes
- Low Res Z
  - 80M = 7 Ohms R + 0j
  - 160M = 8 Ohms R + 0j





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Rain Gutter Dipole	D	A	Shack	C	C	F	F	D	D	C	C	C	D	D	D

PRO
- Install

Off-Center-Fed Spiral Dipole

CON
- On Air

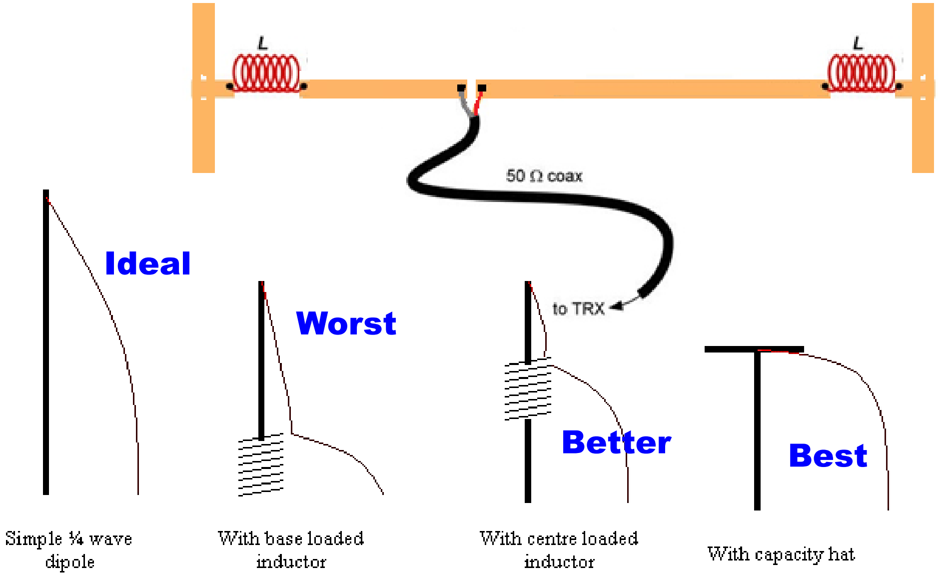
"Off-Center-Fed" Dipole -"Loaded" Dipole

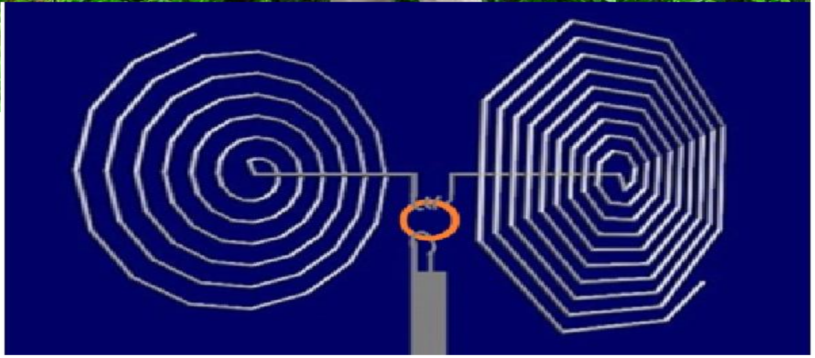
Two short elements with end loads

40M-2M

3 Ft Wide X 3 Ft Tall

~ $10 in Kit Form





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Buddipole	D	C	Shack	B	C	C	C	C	C	D	D	F	F	F	F

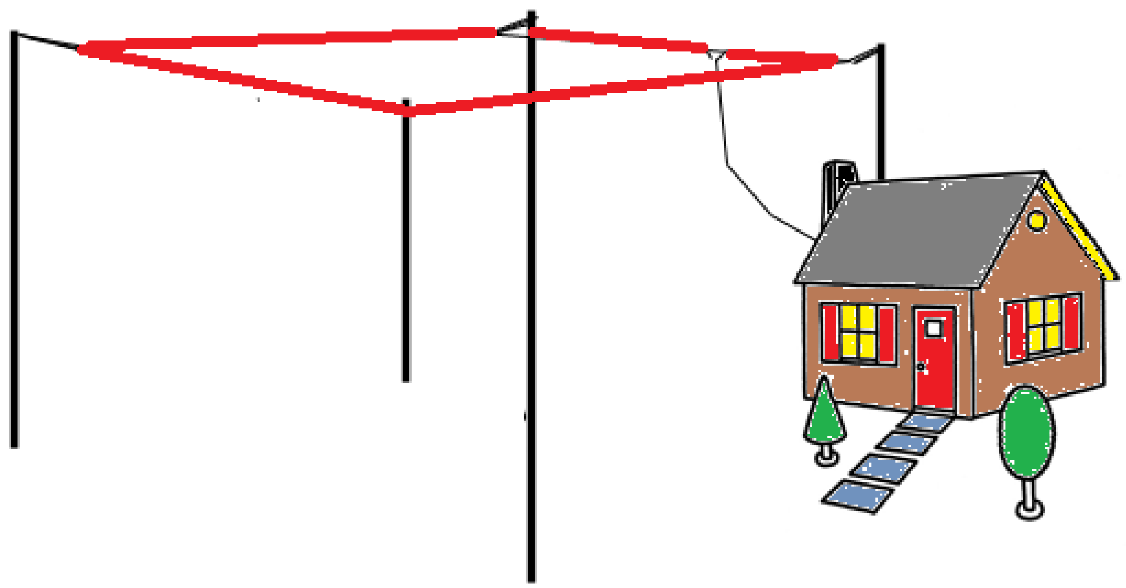
WL Horizontal Loop

Full Wavelength Loop

PRO
- **None?**

CON
- **Install**

Very NVIS Antenna
- Depends on available trees
- Require 60 Feet above ground to work properly
- Low Res Z at 10 – 20 feet above ground



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
WL Horz Loop	D	C	Remote	D	D	F	F	D	D	C	C	C	D	D	D

Rain Gutter Loop

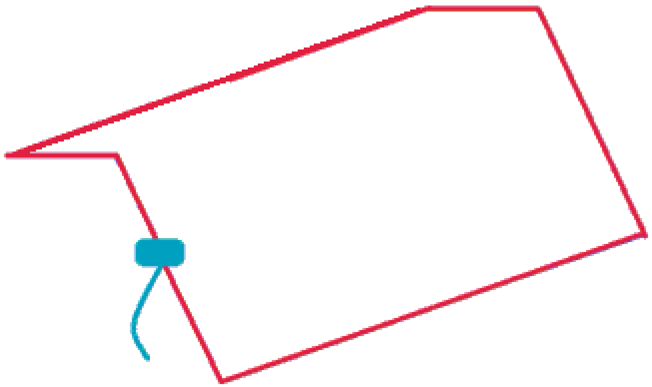
PRO
- **Stealth**

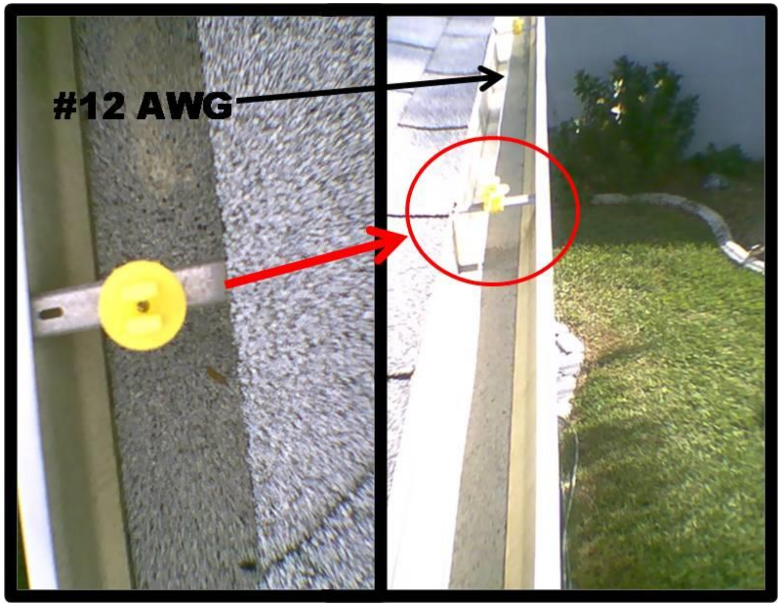
CON
- **On Air**

Full Wavelength Loop

Very NVIS Antenna

- Rain Gutter antenna is a difficult install job
- Keep gutters are isolated from ground install wire on insulators
- Electrical continuity between sections is a maintenance problem
- Coupling to the house, aluminum window and screen cages detunes
- Low Res Z
  - 80M = 7 Ohms R + 0j
  - 160M = 8 Ohms R + 0j





Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Rain Gutter Loop	D	A	Shack	D	C	F	F	F	D	C	C	D	D	D	F

PRO
- On Air

WL Vertical Loop

CON
- 80-160M

Full Wavelength Loop

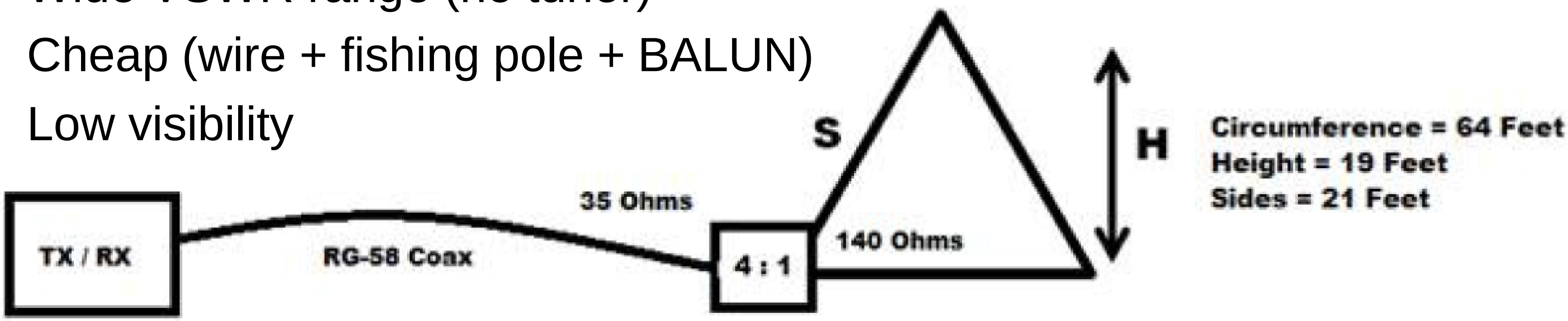
Good on the Air Performance Sitting on Ground

Almost Omni-Directional

Wide VSWR range (no tuner)

Cheap (wire + fishing pole + BALUN)

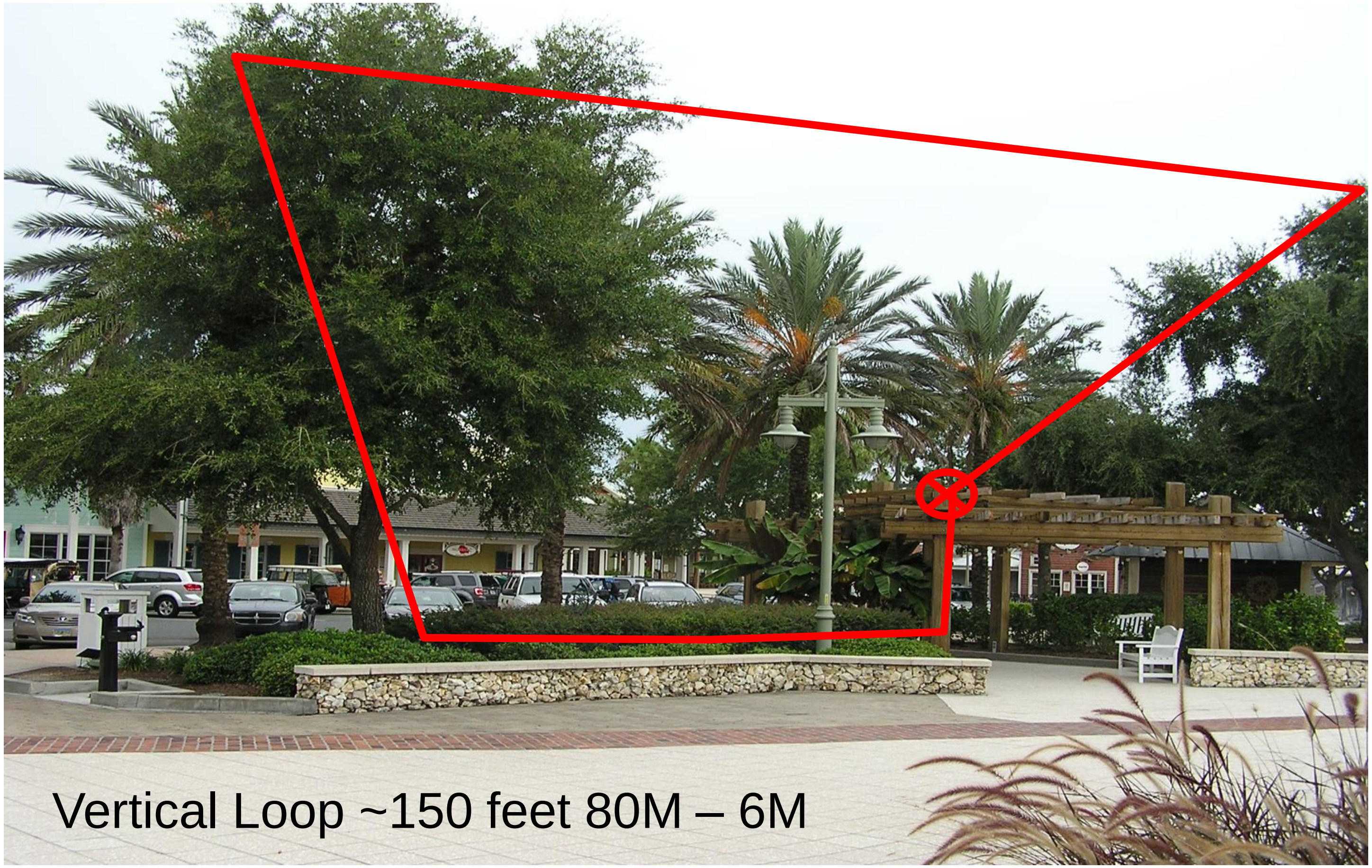
Low visibility



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
WL Vert Loop	B	B	Shack	B	B	B	A	B	A	B	A	B	A	C	F

WL Vertical Loop

Full Wavelength Loop



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
WL Vert Loop	B	B	Shack	B	B	B	A	B	A	B	A	B	A	C	F

Stealth for Sale

Full Loop Go Kit

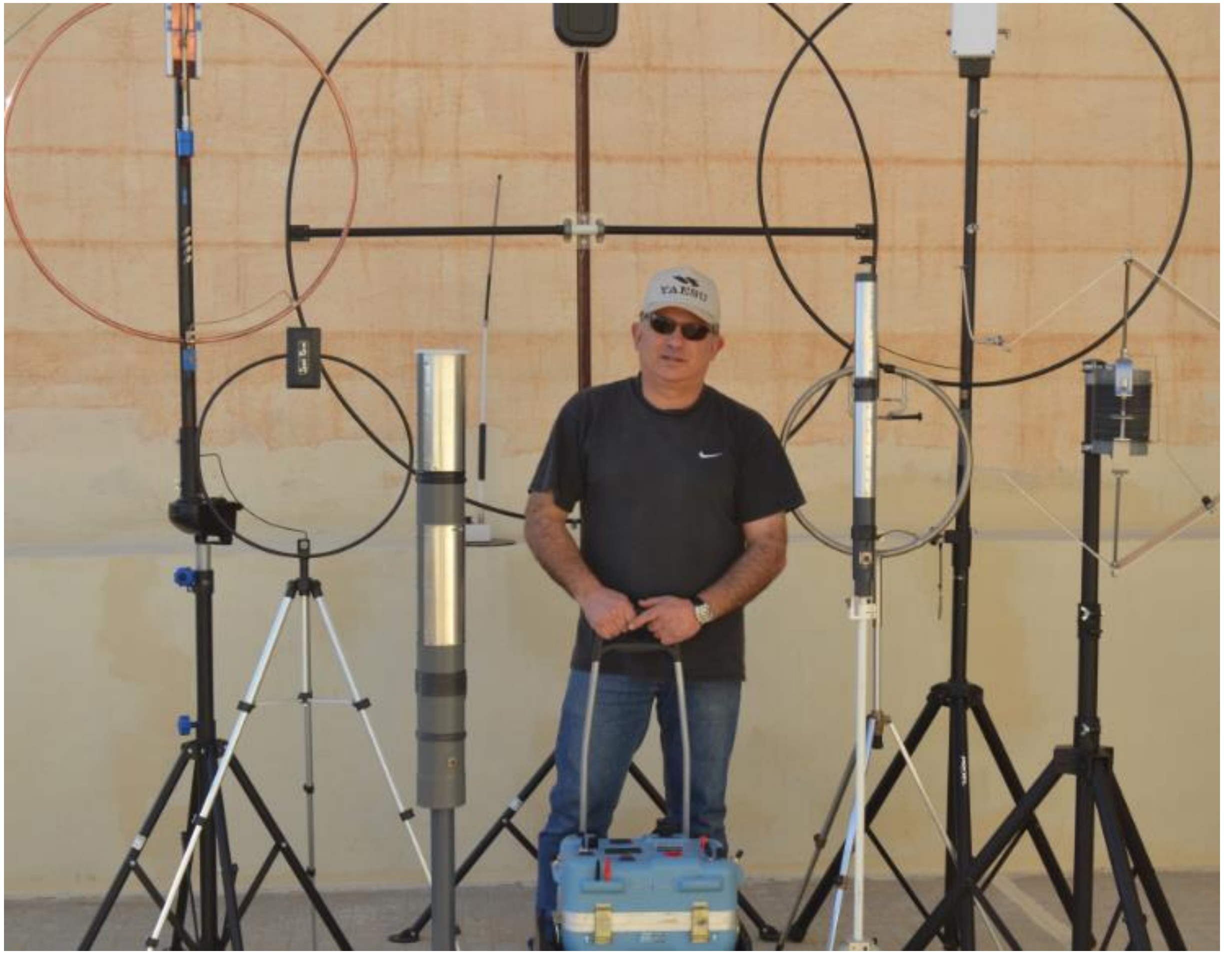
Stealth in a box?

- SG-237 Smartuner
- 80 foot wire.
- Rope
- Cable ties

$400

Magnetic Loop

Short Loop



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

PRO

- **Stealth**

Magnetic Loop

CON

- **Cost**

Short Loop

Short magnetic loops are less than 10% of a wavelength

Magnetic loop does not look like an antenna

Shape can be a circle, rectangle, square, etc. more area helps

RF Efficiency 10% & advanced DIY skill QEX March 2013 P 3-6

Thousands of RF Amps require pipe conductors

Thousands of RF Volts require vacuum capacitors for tuning

10 KHz VSWR Bandwidth

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

Magnetic Loop

Short Loop

MFJ-1786 Loop 30M-10M sells for $500

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

Magnetic Loop

Short Loop

Most Magnetic Loops are DIY

Thousands of RF Amps require pipe conductors

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

Magnetic Loop

Short Loop

Most Magnetic Loops are DIY

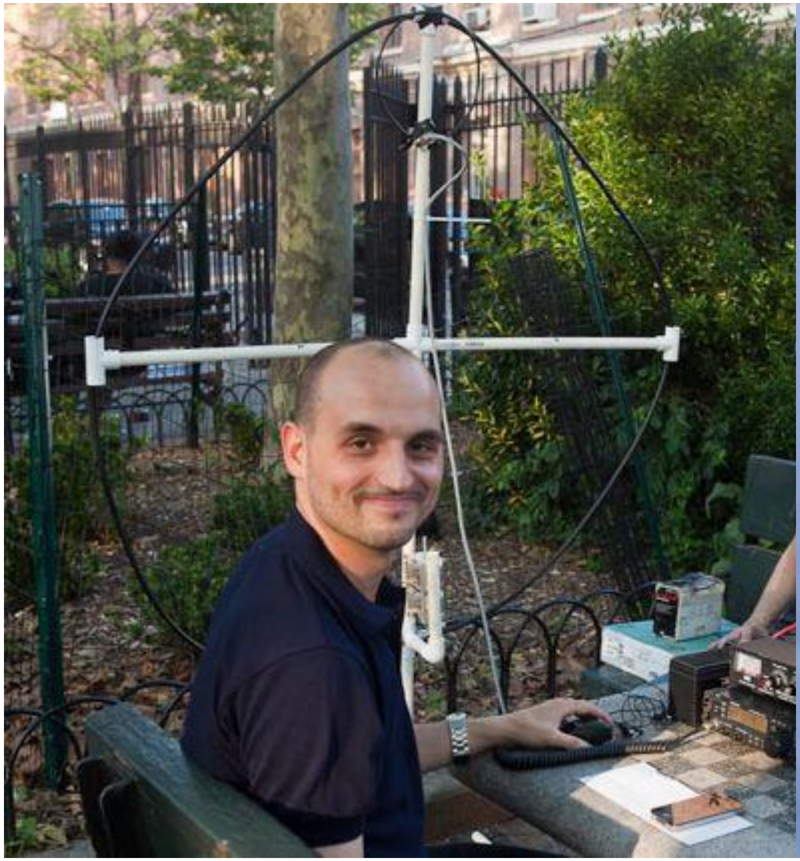
Thousands of RF Volts require vacuum capacitors for tuning

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

Magnetic Loop

Short Loop

QRP Magnetic Loops are often made from coaxial cable or wire



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

PRO

- Stealth

Magnetic Loop

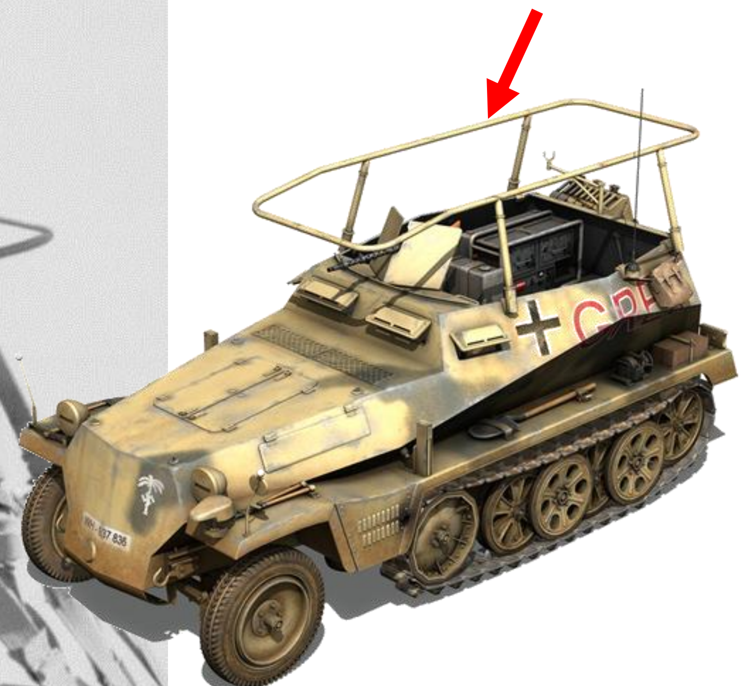
CON

- Cost

Short Loop

Short Magnetic Loops can be used as horizontal loops for short range 200 to 400 Miles NVIS theater communications

Mag Loop



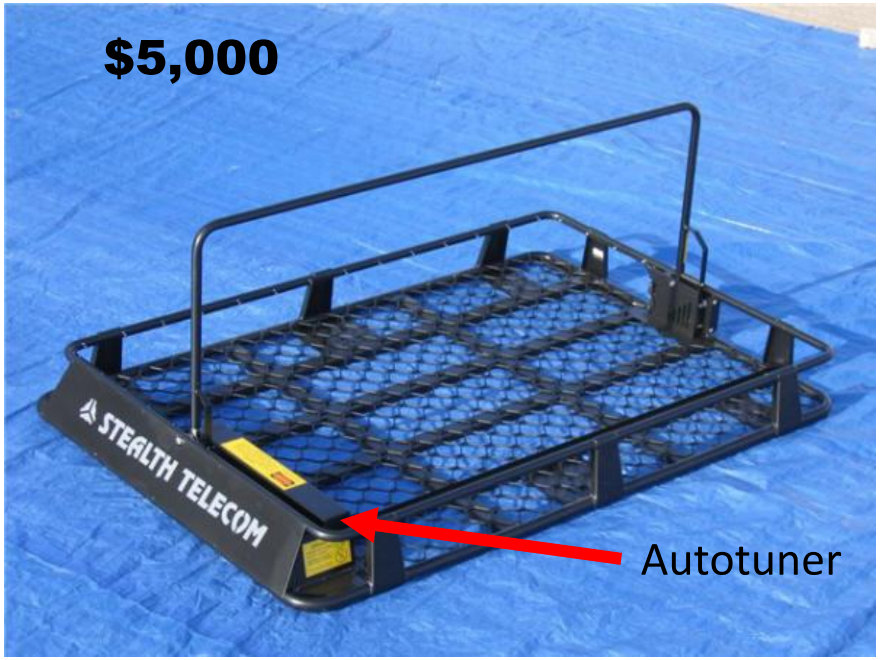
Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

Magnetic Loop

Short Loop

Vertical or horizontal loops mobile communications

Stealth Telecom 9400 Mobile HF NVIS Magnetic Loop Antenna



Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

Magnetic Loop

Short Loop

Vertical DIY loops mobile communications

Antenna	On Air	Stealth	Tuner	Install	Cost	6M	10M	12M	15M	17M	20M	30M	40M	80M	160M
Magnetic Loop	C	A	F	B	D	C	C	C	C	C	C	C	D	D	D

PRO

- **Cost**

2M / 70cm

CON

- **None?**

The Villages have good 2M & 70cm repeater coverage

Most can reach one or more repeaters from an HT

An attic antenna will reach the five Sumter repeaters

Newer homes with aluminum roof sheathing require stealth antennas

PRO
- Cost

2M / 70cm

CON
- None?

Simply the Best

Does NOT require a ground plane.

Mount on a metal mast

Ideal for mounting in an attic,
On a roof vent pipe, (up to 1 1/2")
On a wooden or Fiberglass pole,
On Fiberglass or Plastic Vehicles,
(Motorhomes, Trucks, **Boats**)
Mount it just about anywhere.

Low SWR - Wide Bandwidth

Has Gain over a 1/4 wave .

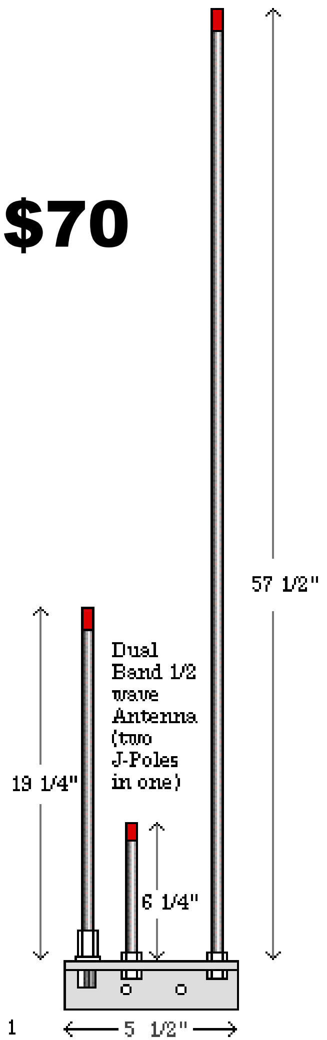
Omni-Directional.

This is a very Heavy Duty Antenna.
The Elements are made from 3/8"
Solid Round Aluminum with a Heavy
Duty Angle Mounting Bracket.

Mounting Hardware for
mast up to 1 1/2" Included.

Single SO239
Feed Connector

$70



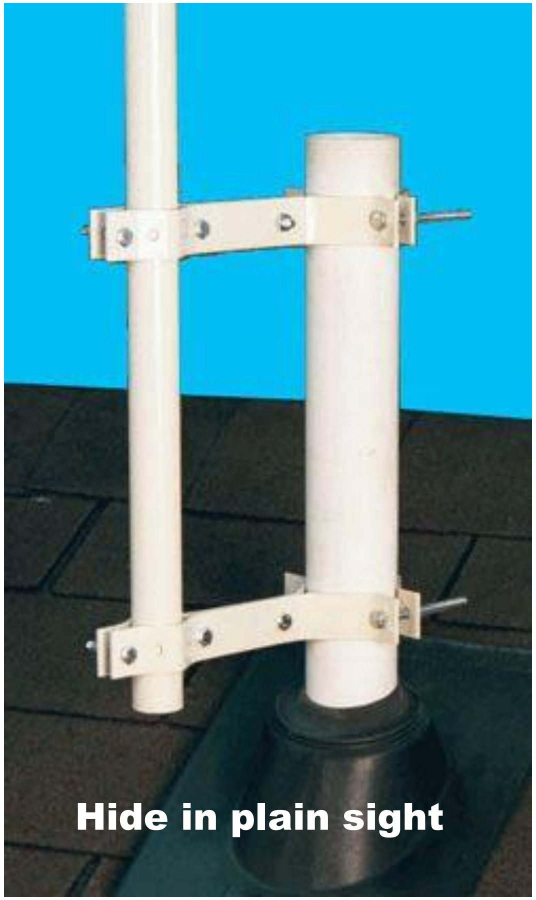
Arrow J-Pole

· 1

Covers 143-149 MHz. VHF
Covers 437-450 MHz. UHF
With an VSWR of less than 1.5 - 1

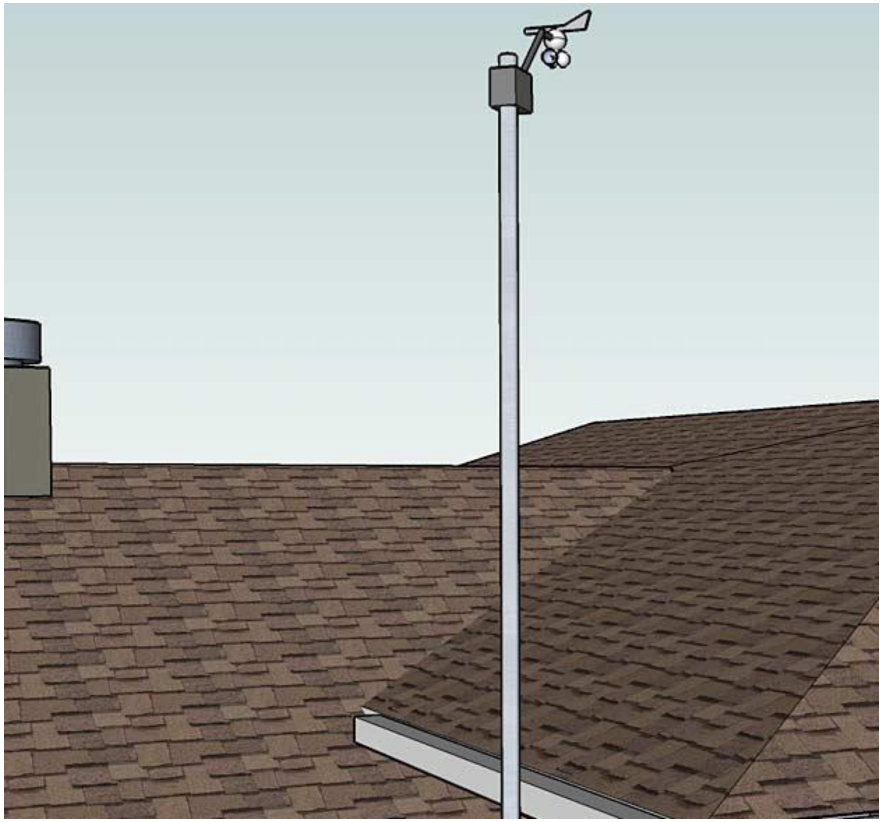
2M / 70cm

Most 2M & 70cm antennas will fit inside PVC pipe & mount as a vent pipe



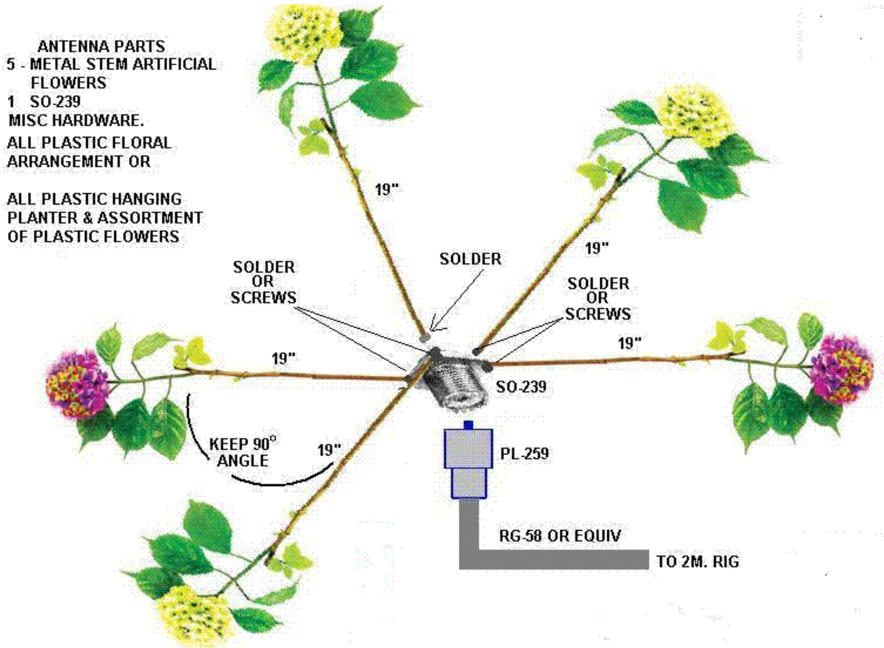
2M / 70cm

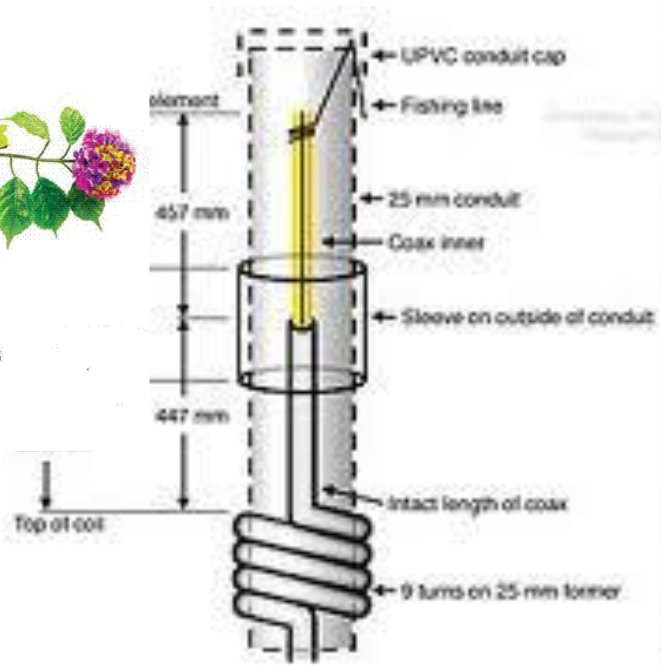
Most 2M & 70cm antennas will fit inside PVC pipe & accent with a plastic weather vane



2M / 70cm

More 2M & 70cm antennas stealth options; hiding as a potted plant or staked tree, climbing vine, etc.





Antennas for The Villages

Modulation matters more than your antenna or power output

- AM vs. SSB vs. CW vs. PSK vs. JT65
- 5 W using CW equals 250 W using SSB
- 5 W using PSK-31 equals 2,500 W using SSB
- QST Dec 2013, P30-32

Height (of Dipoles, G5RV, End Fed) matters, except Vert Loops

- Horizontal elements near ground are NVIS
- QST Nov 2009, P 64-65 - May 2010, P 57 - Apr 2010 P 47-48

Short Antennas hurt RF Efficiency

- Loads at base hurt, top loads help, top caps help
- Traps hurt lower frequencies
- QEX Jan 2014, P34-42 – Mar 2014, P18-31

1 Counterpoise above ground = 32 Radials

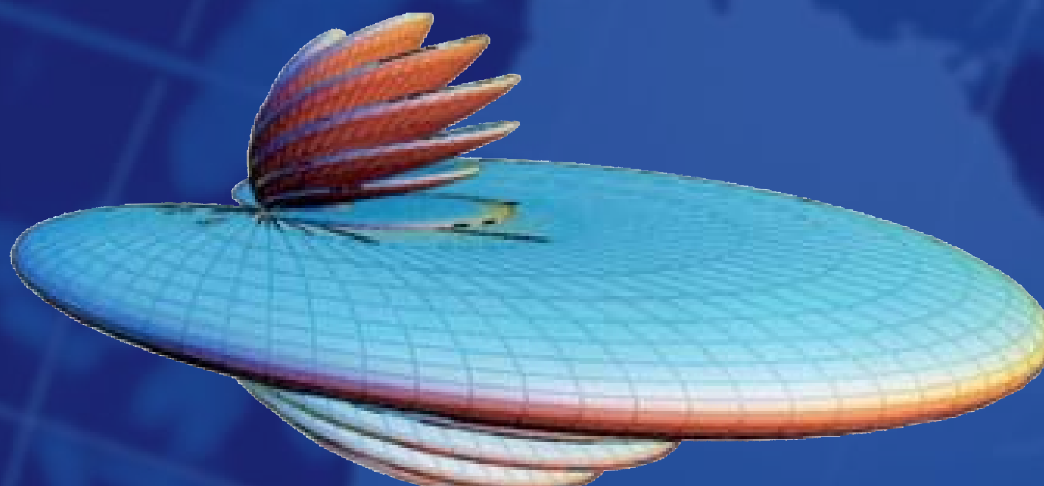
- Poor soil conductivity hurts radials as counterpoise
- QST Mar 2010, P30-33 – Mar 2014, P35-37

Some timeless approaches for better RF performance

- Anything Tall Helps (except Vertical WL Loops any height works)
- Longer is better (monopole objective is ¼ WL or odd multiples, ½ WL for dipoles)
- Inverted-L address lower frequencies (160M-40M)
- *Vertical WL Loops* address most HF bands (80M-10M)

Antenna Theory

Basic Principles for Practical Applications



T-Mobile
Get more from life

ANDREW

2004

Outline

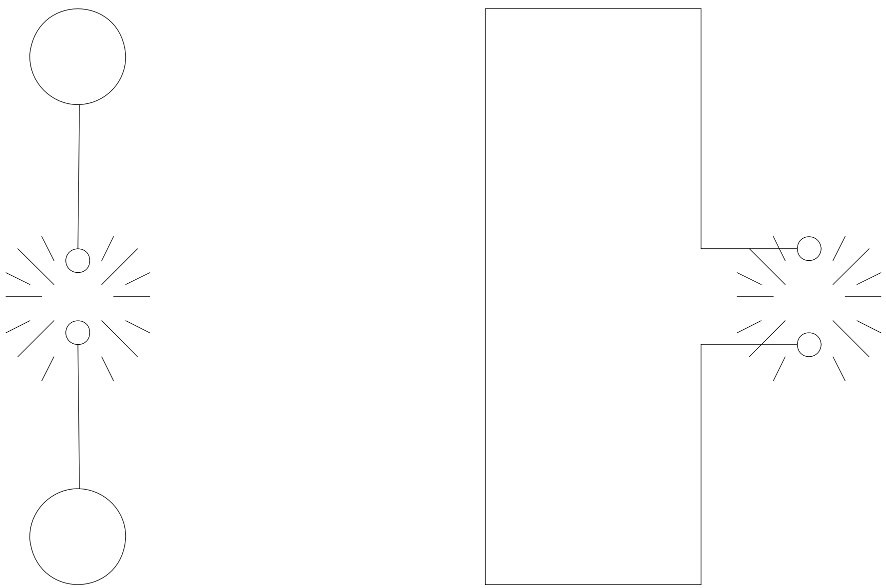
- Brief History
- Antenna Building Blocks
- Antenna System
- Antenna System Tests
- Radiation
- Antenna Performance
- Break
- Antenna Construction
- Pattern Evaluation
- Cell Planning Considerations
- Down Tilt
- Break
- Intermodulation Interference
- Obstructions
- Antenna Concealment
- New Concepts

Pioneers of EM Theory & Antennas

- Thales (600 BC): Observed sparks when silk rubbed on amber, natural stones attracted
- Gilbert (1600 AD), Franklin (1750), Coulomb, Gauss, Volta (1800), Oersted (1819), Ampere (1820), Ohm, Faraday, Henry (1831), Maxwell (1873)

The First Antenna

- Heinrich Rudolph Hertz's (1886) built first radio system:



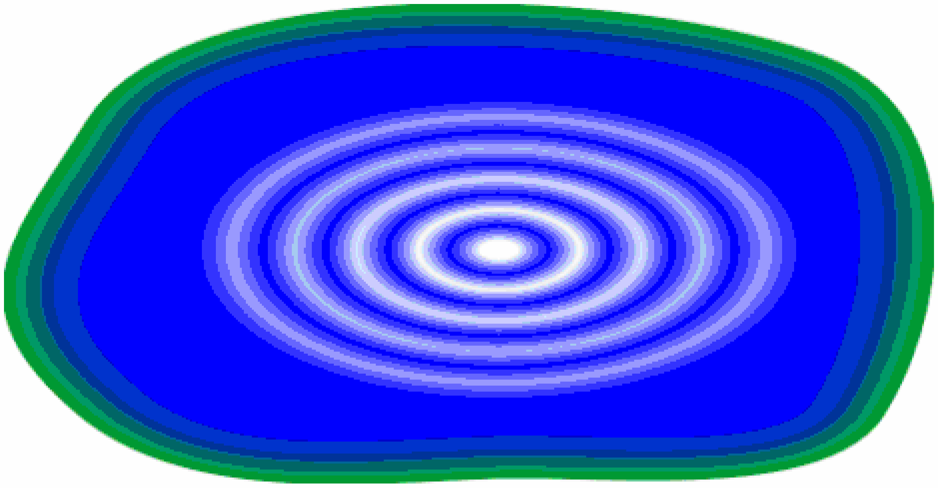
The First Wireless (Radio)

- Guglielmo Marconi:
  - Repeated Hertz’s experiments
  - Built first radio system to signal over large distances: England to Newfoundland
  - Proved radio waves bend around earth
  - Also applied technology to ships

Radio Waves

Are "vibrations" of electromagnetic energy travelling through space

- A bit like ripples on the top of a pond



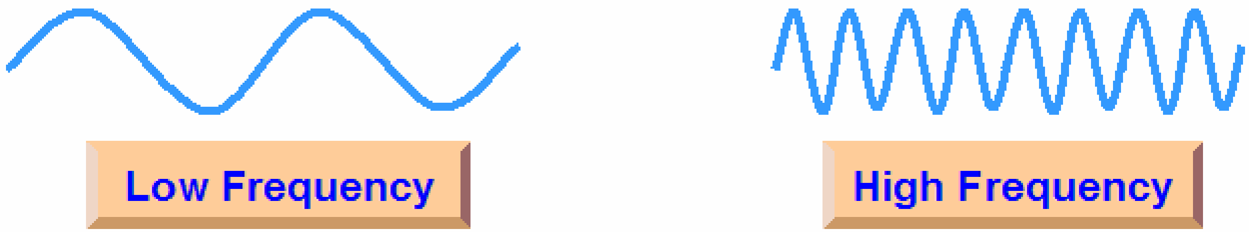
They travel through space at 300,000,000m/sec (ie 1,080,000,000 km/hr)

The waves get weaker as they travel

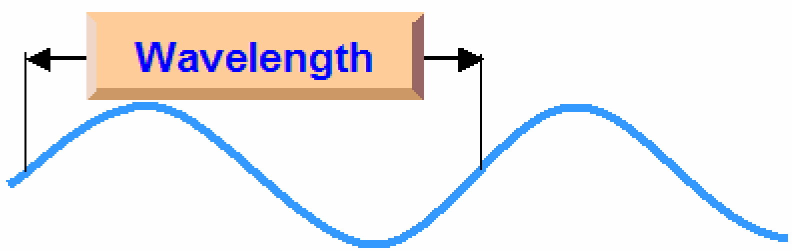
Frequency and wavelength

- Frequency is the rate of "vibration"

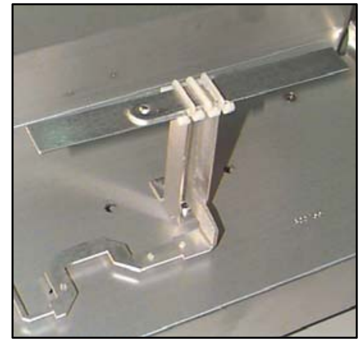
  or the number of waves that go past in one second (ie cycles per second, called Hertz, or MegaHertz for millions of cycles per second)

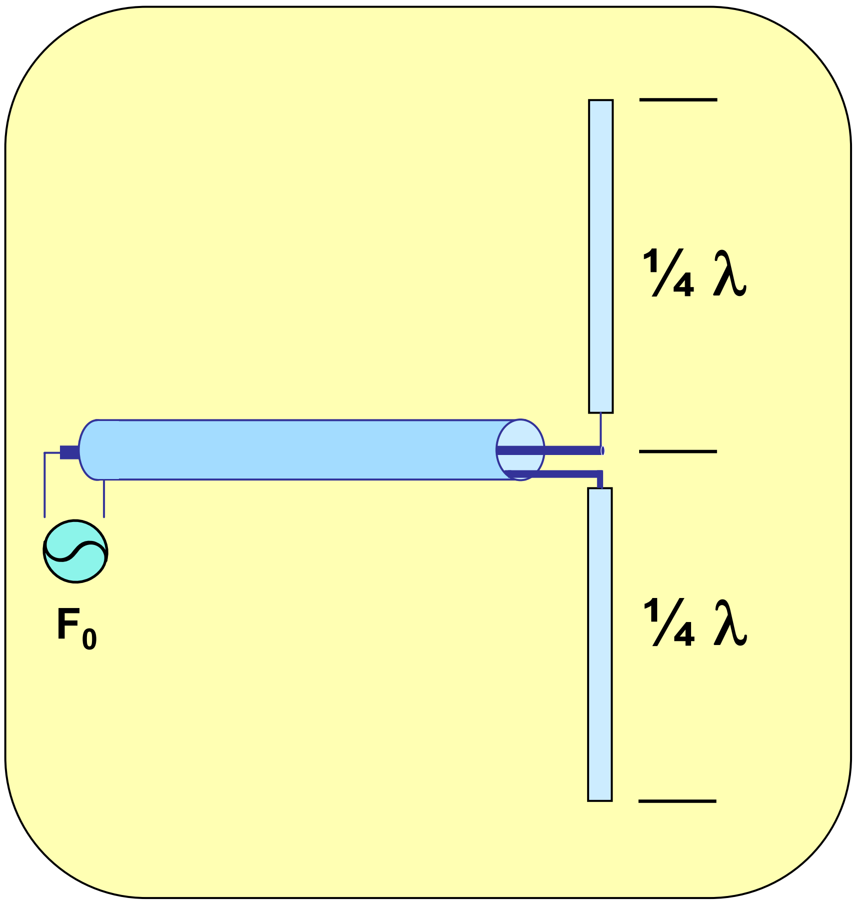


Wavelength is the distance between successive waves as they travel along



Dipole

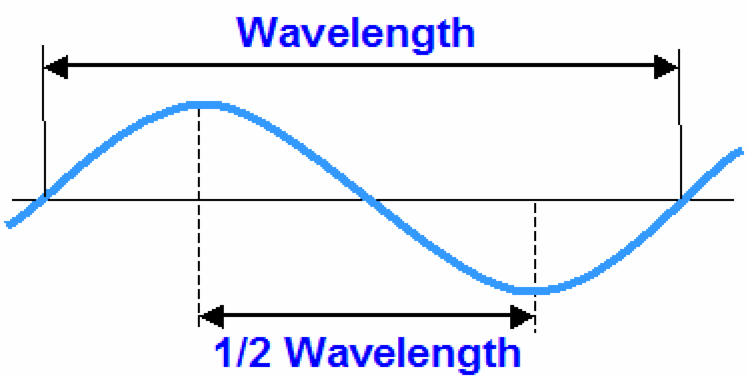


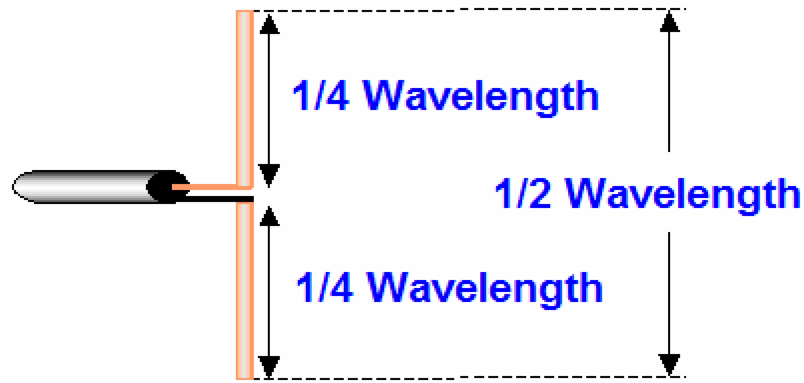


F_0 (MHz)	λ (Meters)	λ (Inches)
30	10.0	393.6
80	3.75	147.6
160	1.87	73.8
280	1.07	42.2
460	0.65	25.7
800	0.38	14.8
960	0.31	12.3
1700	0.18	6.95
2000	0.15	5.90

Dipoles

- Dipoles are a commonly used as radiating elements in an antenna.
- The length of a dipole is proportional to the wavelength.



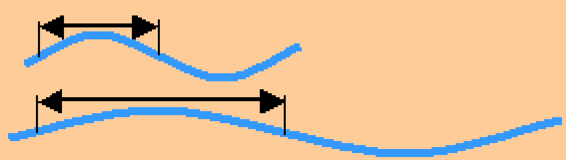


Dipole

A 1/2 wavelength dipole at

800MHz is ~200mm long

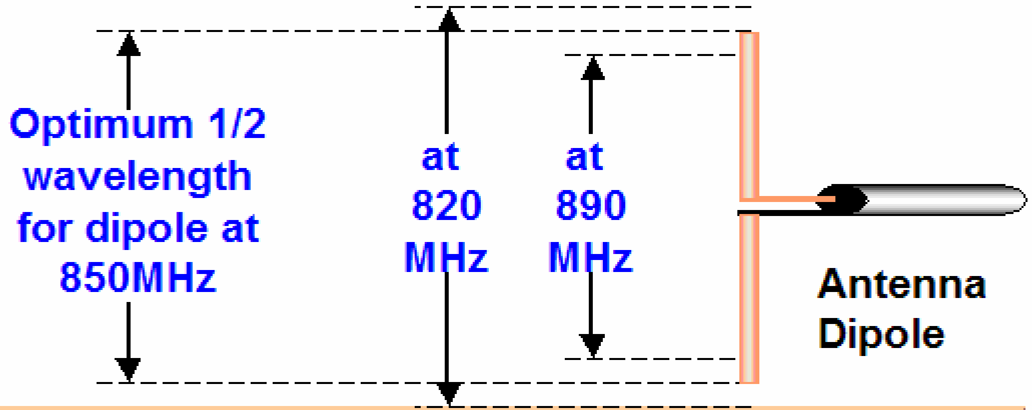
400MHz is ~400mm long



Frequency Range

Performance remains acceptable in the frequency range

- Performance reduces when wavelength is not optimum



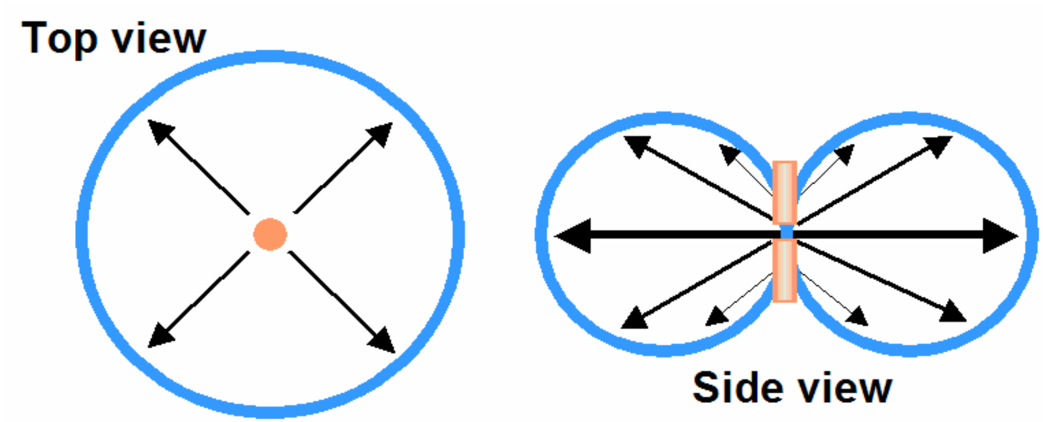
1/2 wavelength at 820 MHz ~ 180mm, and at 890 MHz ~ 170mm

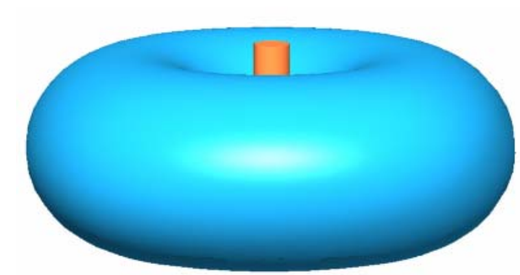
The antenna optimised for 850MHz will be ~ 175mm long

The antenna bandwidth = 890 - 820 = 70MHz

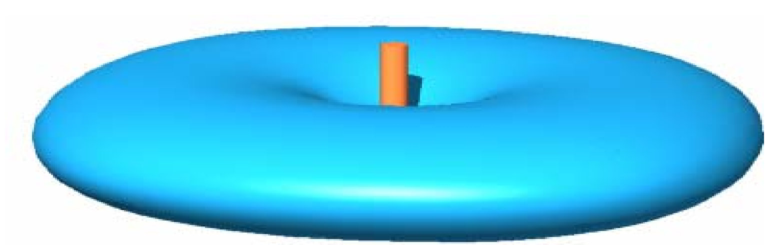
Dipoles and the Antenna

A single dipole has a “doughnut” shaped pattern



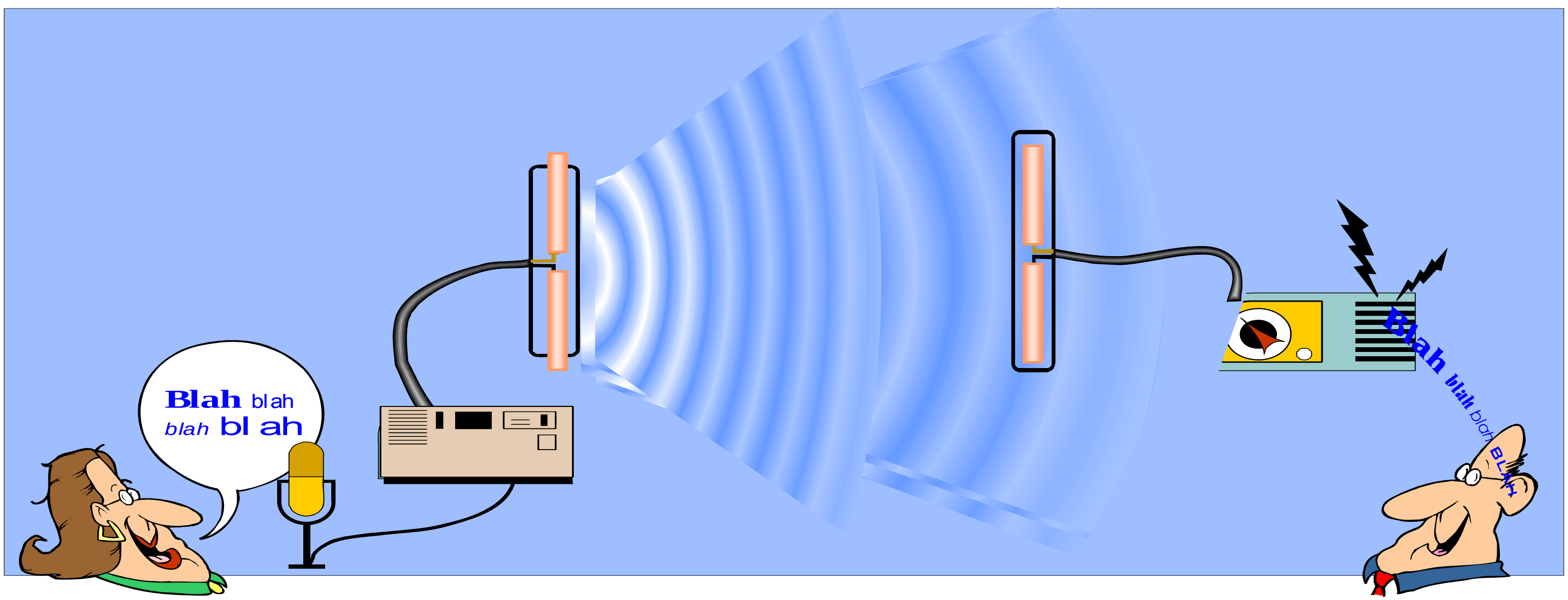


- Need to “flatten” the “doughnut” to concentrate the signal to where it is wanted, at ground level

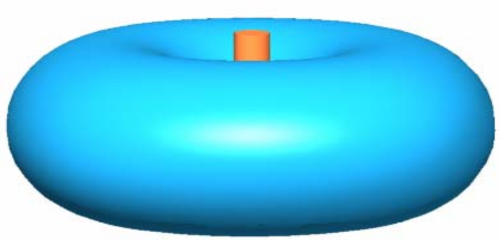


Understanding the Mysterious "dB"

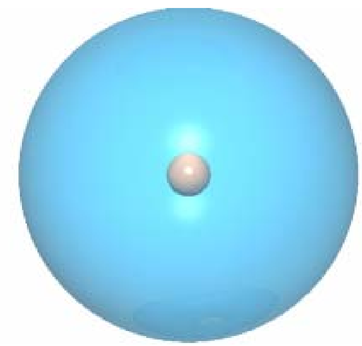
- A dB is 1/10th of a "Bel" (Named after Alexander Graham Bell)
- A dB is measured on a logarithmic scale
- A dB or "Decibel" originally comes from quantifying signal strengths in terms of relative loudness as registered by the human ear
- dB in the RF world is the difference between two signal strengths



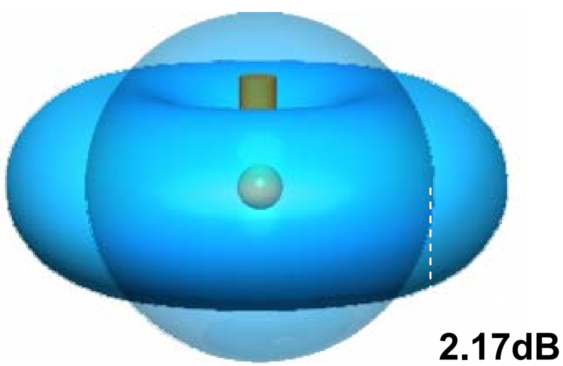
dBd and dBi



A single dipole radiates with a doughnut pattern



An isotropic radiator radiates equally in ALL directions



The dipole is 2.17dB higher in gain

The gain of an antenna compared to a dipole is in “dBd”

The gain of an antenna compared to an isotropic radiator is in “dBi”

eg: 3dBd = 5.17dBi

“dBm and dBc”

“dBm” – Absolute signal strength relative to 1 milliwatt

1 mWatt	=	0 dBm
1 Watt	=	+30 dBm
10 Watts	=	+40 dBm
20 Watts	=	+43 dBm

Note: The Logarithmic Scale
$10 \times \log_{10}$ (Power Ratio)

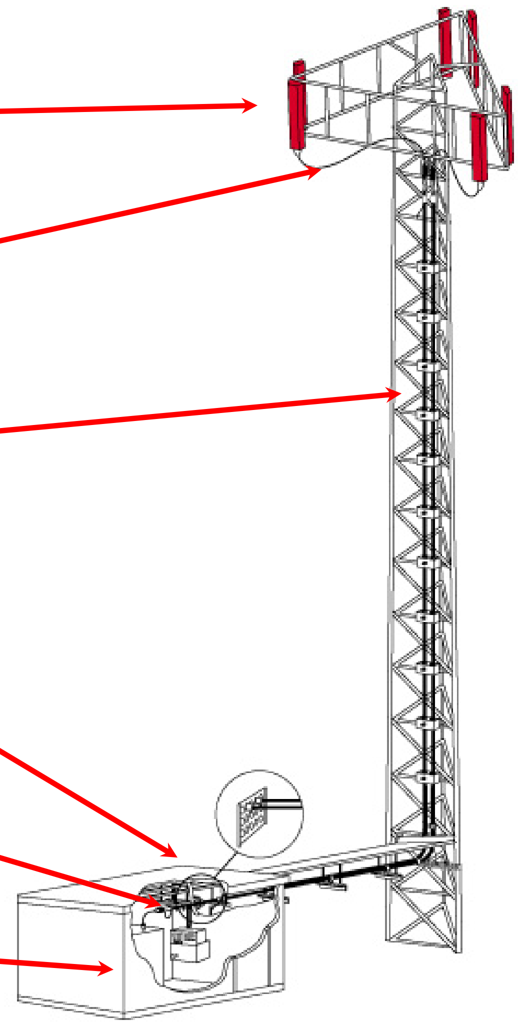
“dBc” – Signal strength <u>relative</u> to a signal of known strength, in this case: the <u>carrier</u> signal

How and why is dBc used with base station antenna specs?

Pay attention – Group quiz later!

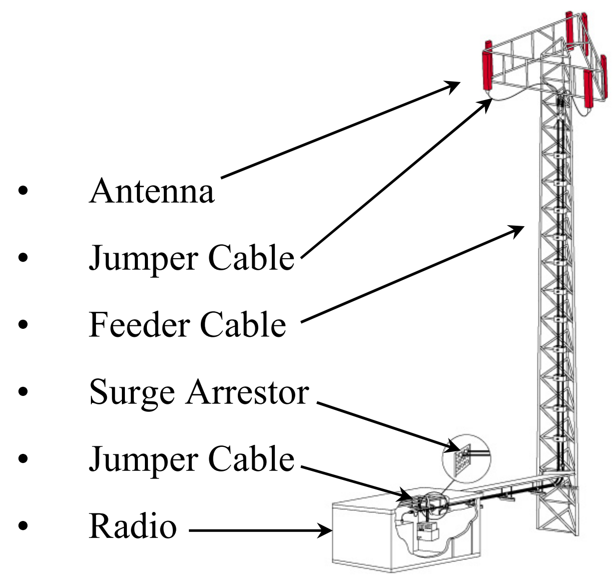
Basic Antenna System

- Antenna
- Jumper Cable
- Feeder Cable
- Surge Arrestor
- Jumper Cable
- Radio



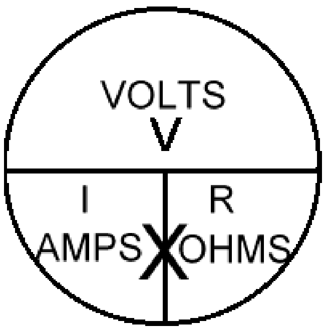
Full System Sweep

- 3 different tests
  - Return Loss
  - VSWR
  - Distance to Fault (DTF)



Impedance

- These 3 tests measure the reflected voltages caused by change of impedance in a transmission line.
- Impedance is measured in ohms (Ω).



$$V = I \times R$$

or

$$V = I \times Z$$

where Z is defined as impedance and is complex

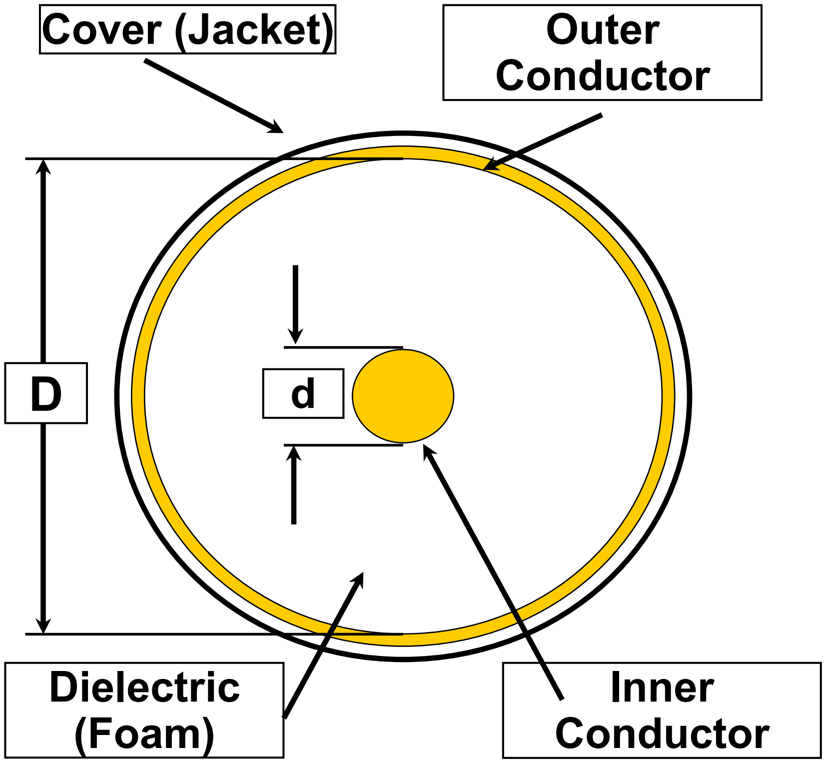
$$Z = R + j\,X$$

R = resistance and X = reactance both measured in ohms

Examples:

- Wireless = 50Ω
- Old TV = 300Ω
- Cable TV = 75Ω

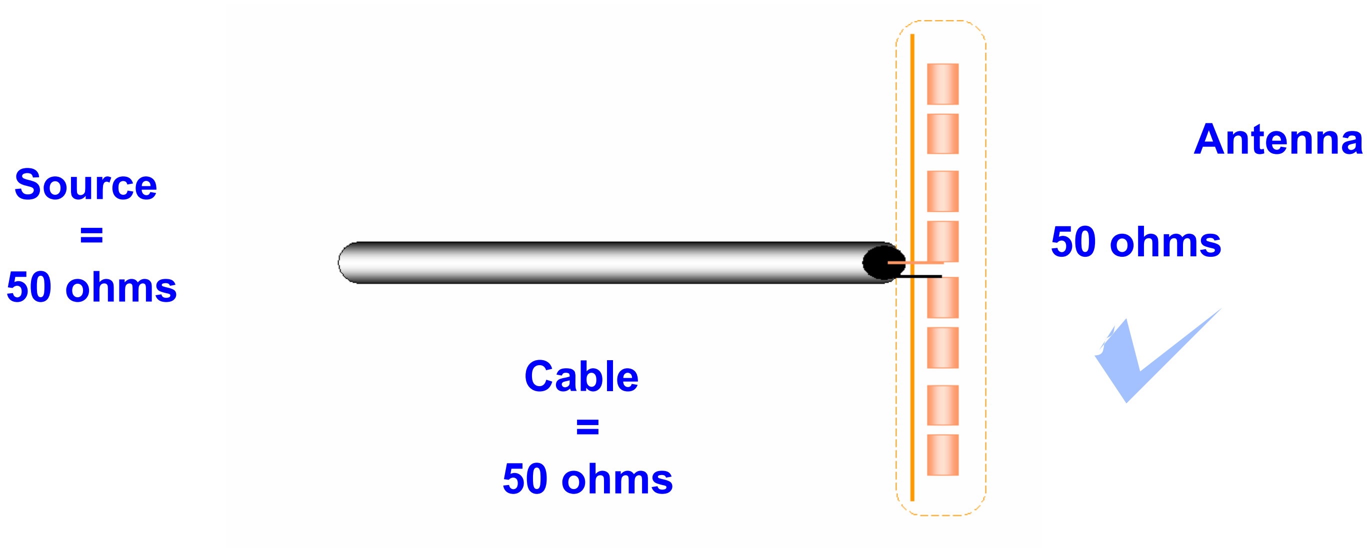
Impedance



History note:

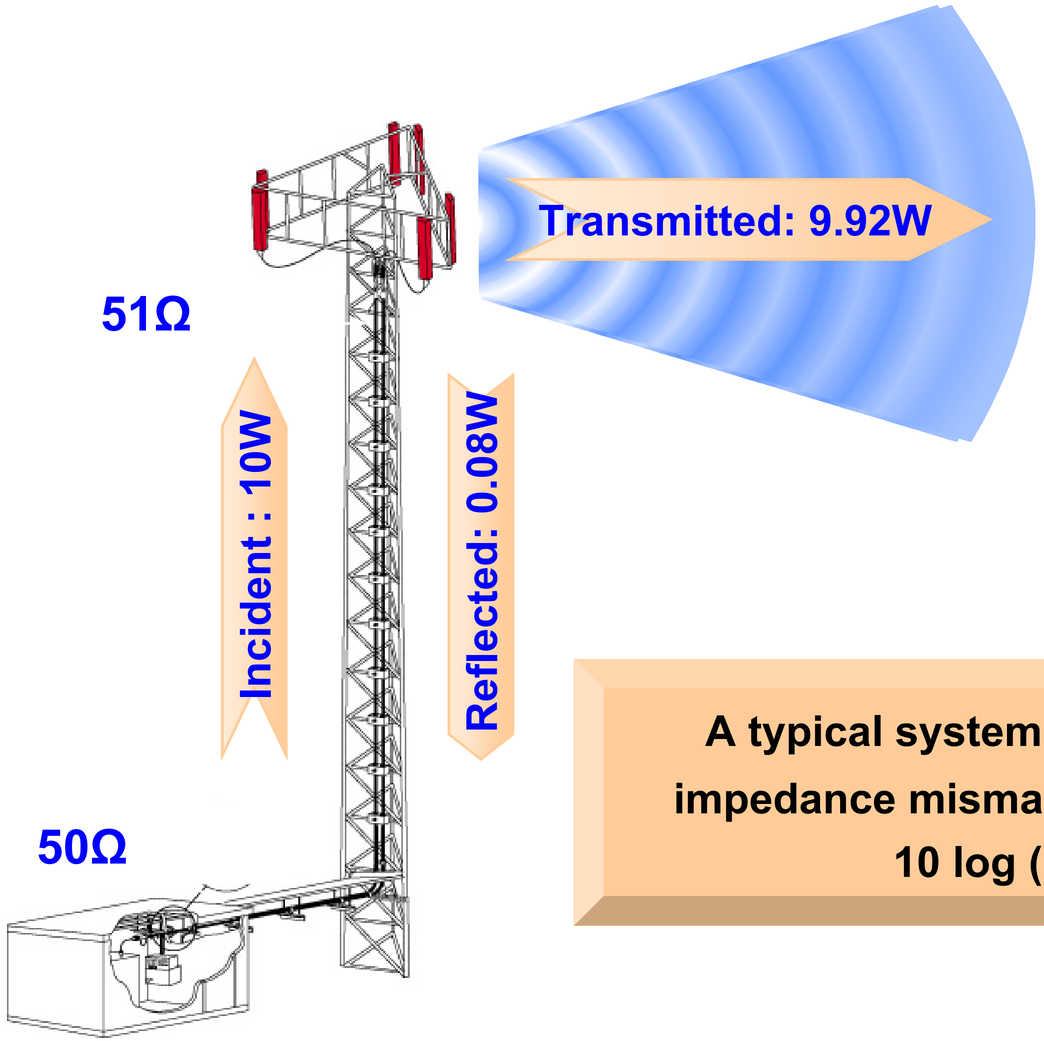
•Older CATV coax had air dielectric utilizing plastic disc's to support the center conductor.

Impedance



Match!

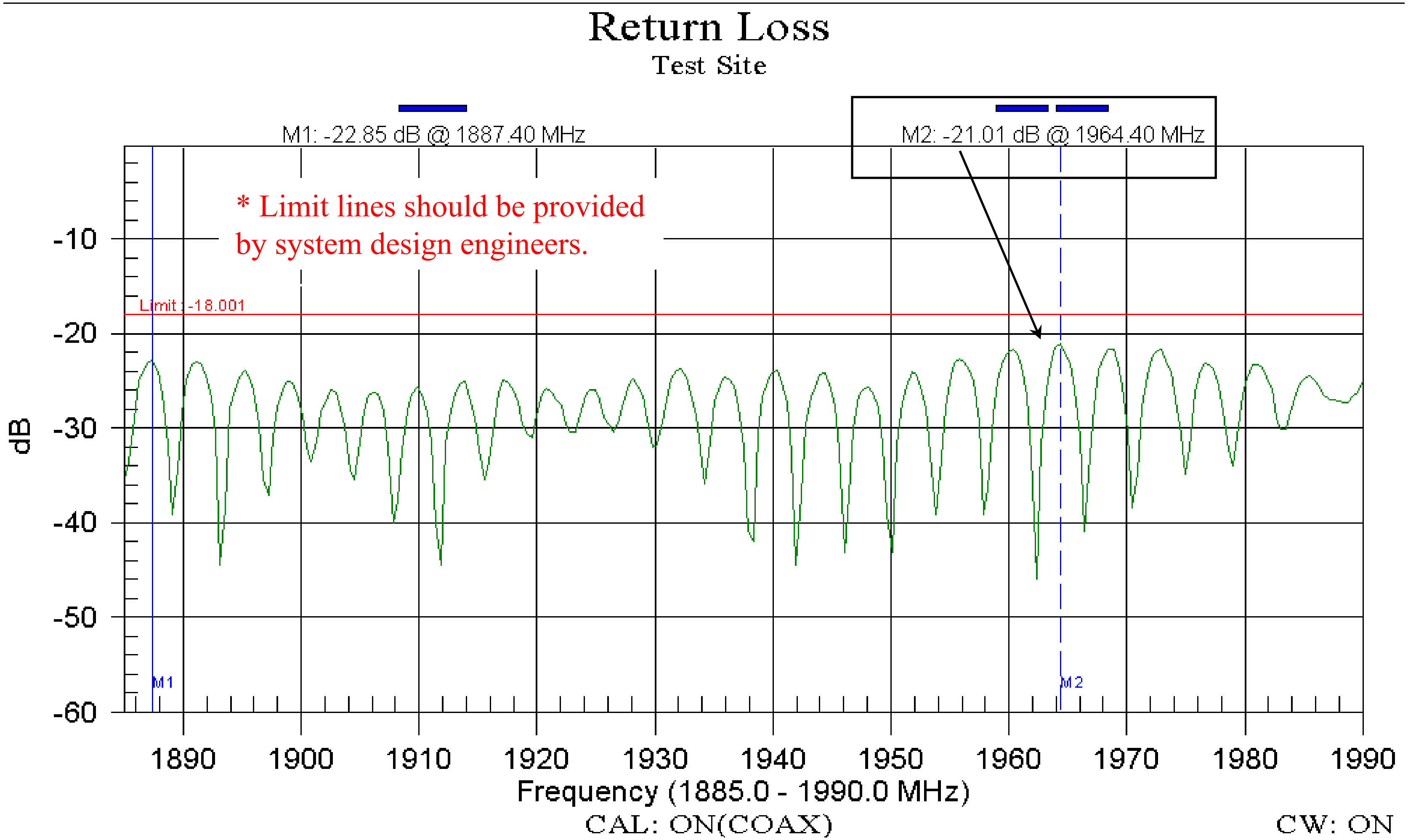
Return Loss



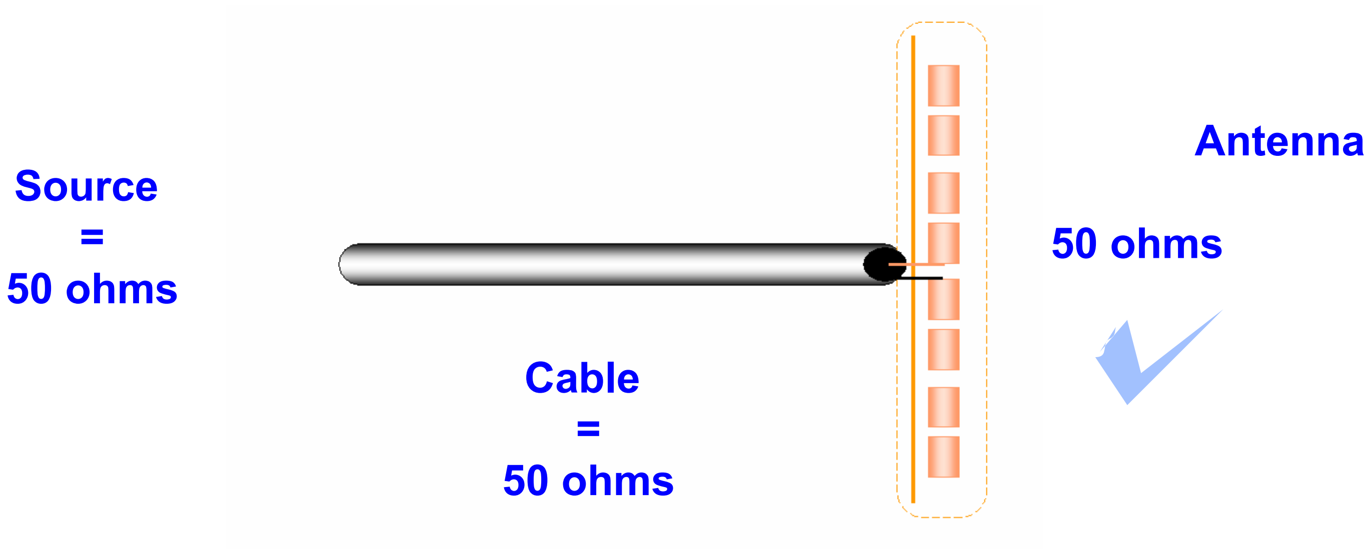
A typical system *always* has some nominal impedance mismatch. Here the Return Loss is

10 log (0.08 / 10) = -21dB **PASS!**

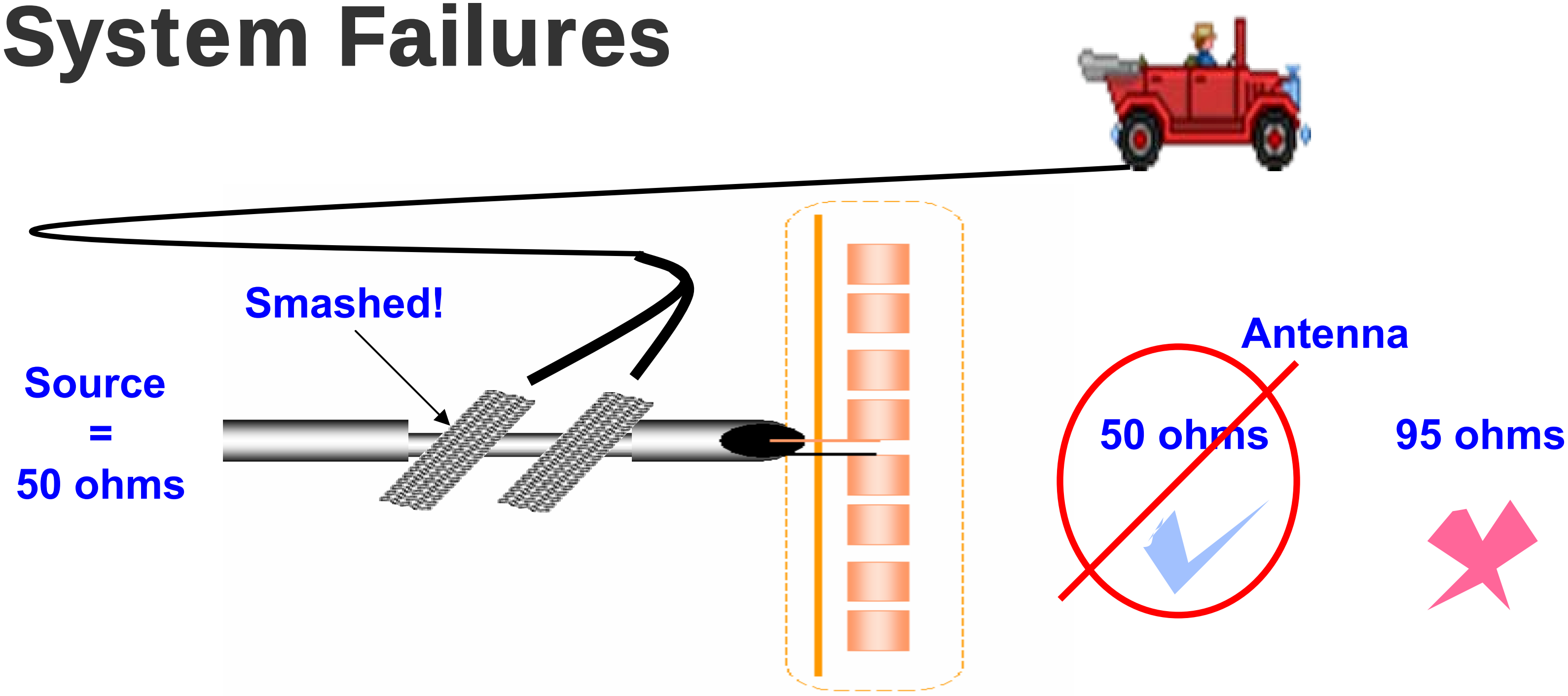
Return Loss


Return Loss
Test Site
M1: -22.85 dB @ 1887.40 MHz
M2: -21.01 dB @ 1964.40 MHz
* Limit lines should be provided
by system design engineers.
Limit : -18.001
dB
-10
-20
-30
-40
-50
-60
M1
M2
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Frequency (1885.0 - 1990.0 MHz)
CAL: ON(COAX)
CW: ON

System Failures



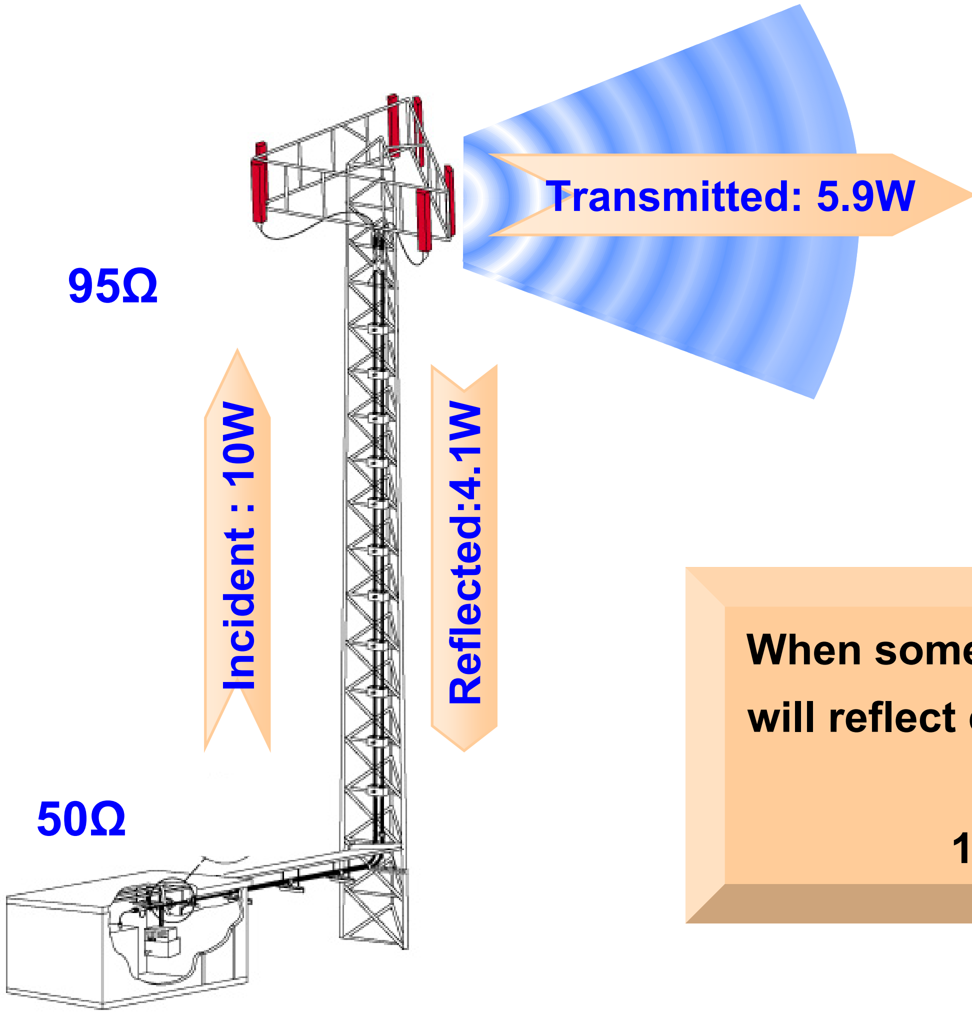
System Failures



Mismatch!

When an impedance mismatch occurs in an RF subsystem, an amount of RF energy is reflected back to the source.

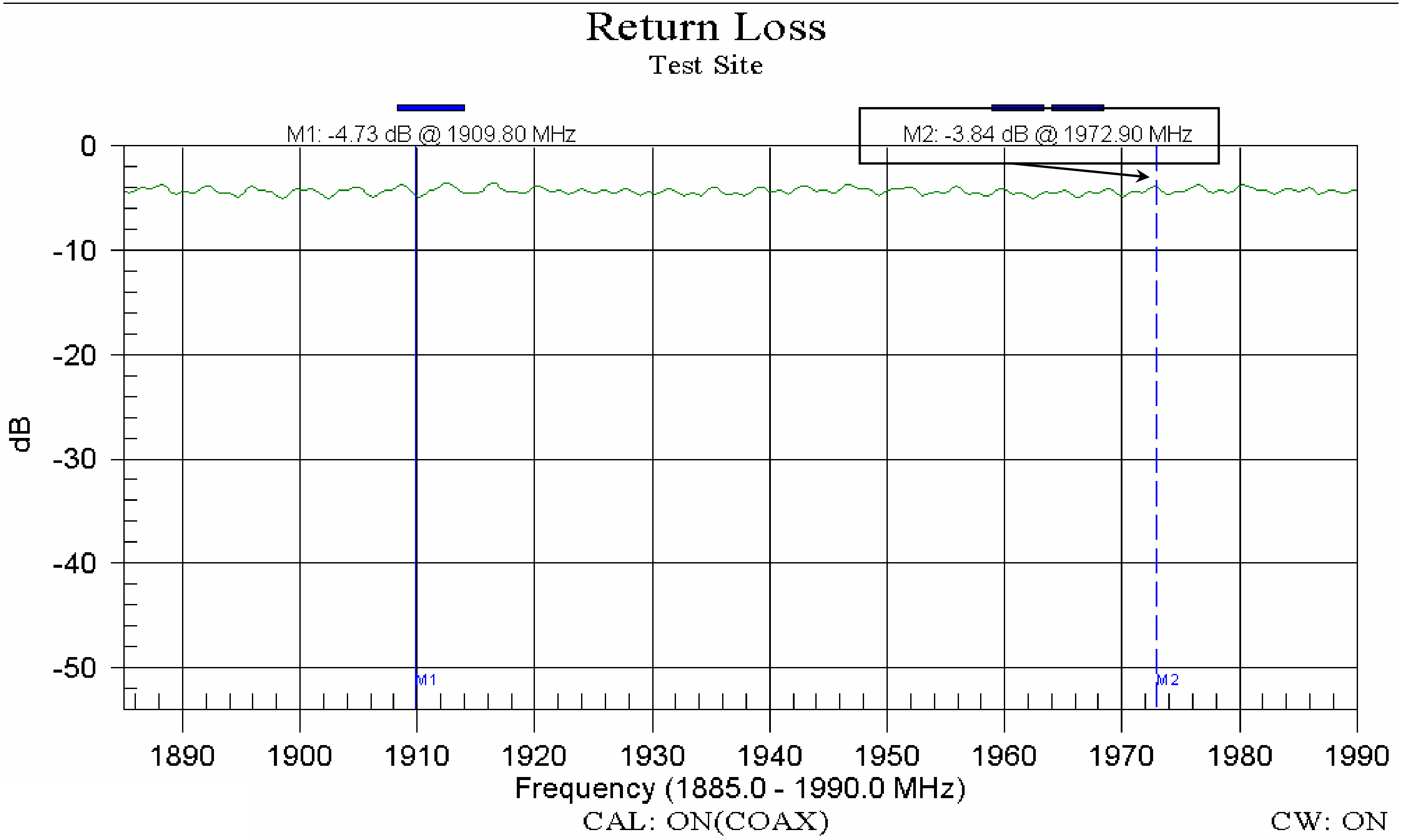
System Failures



When something is wrong, much more energy will reflect causing performance failures. Here the Return Loss is

10 log (4.1 / 10) = -3.87dB FAIL!

System Failures



System Failures

Mini Group Quiz!

What is the "standard" torque spec of a 7/16 DIN?

A) 18 to 22 ft-lbs.

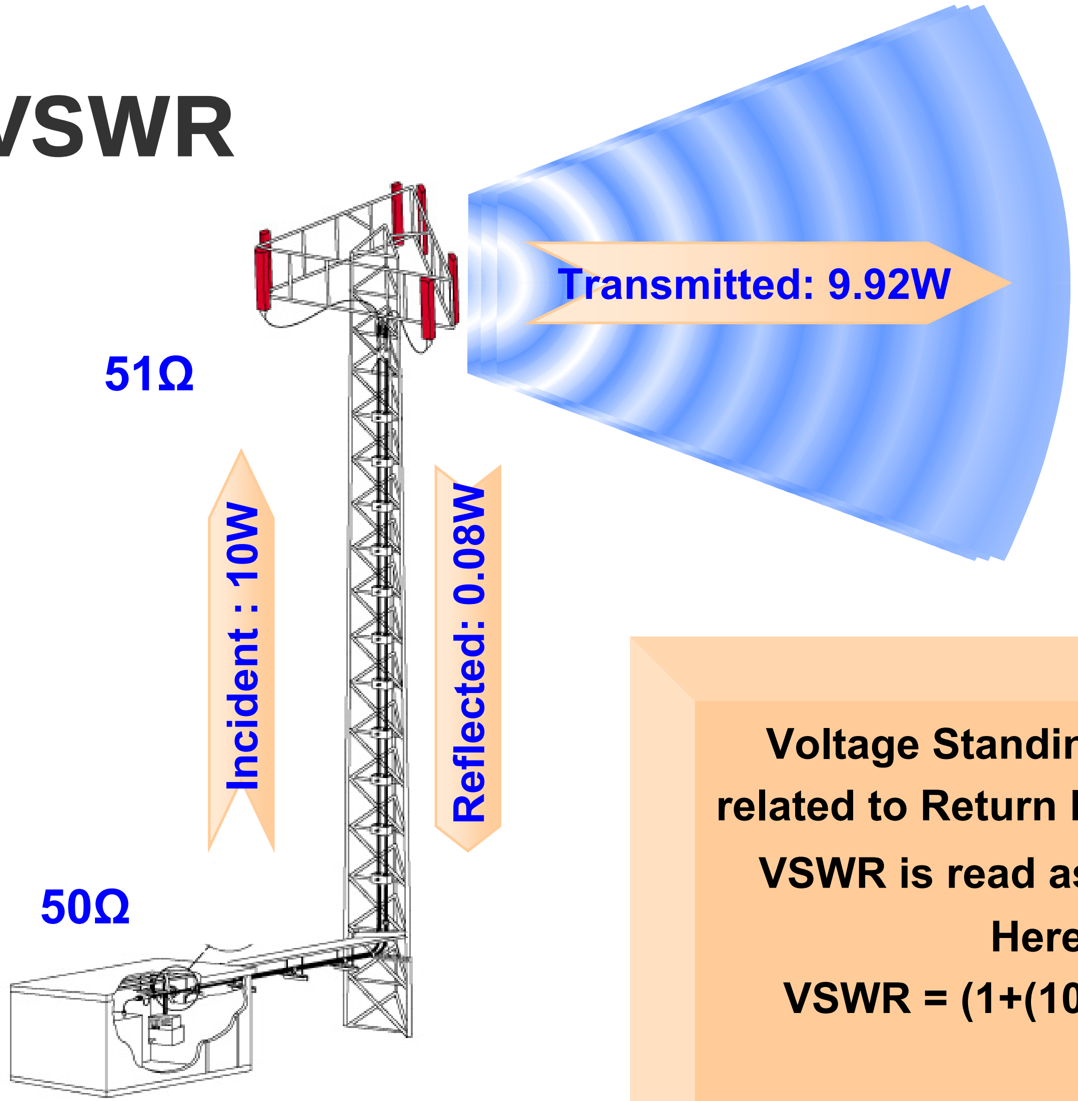
B) 50 to 55 ft-lbs. **A**

C) 122 to 127ft-lbs

"Positive Stop" Connector
- up to 70 ft-lbs

RF components have some reflection but damaged components will cause larger reflections and in that case creates a system to fail.

VSWR



Voltage Standing Wave Ratio (VSWR) is related to Return Loss. The difference is that VSWR is read as a ratio instead of in dB.

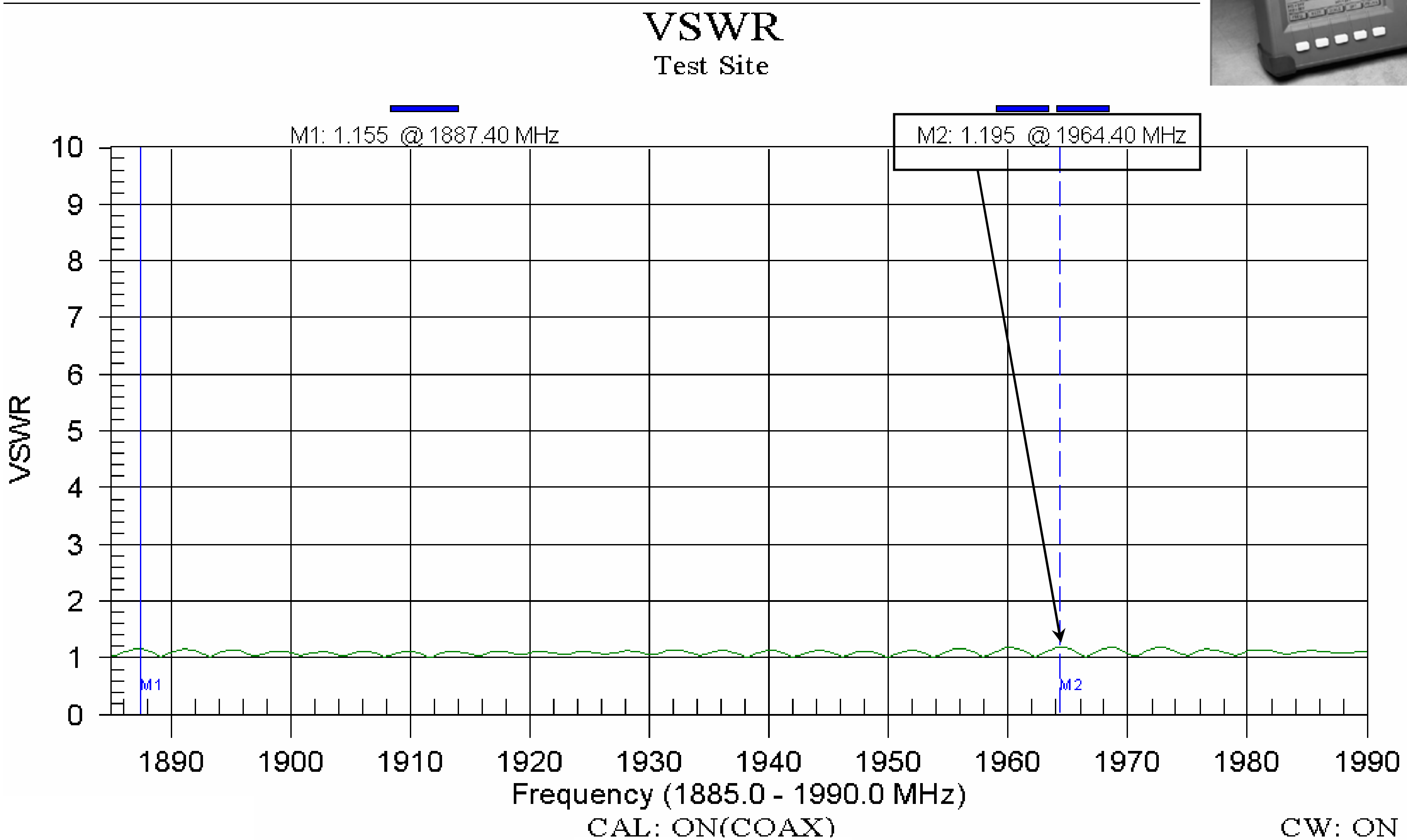
Here the VSWR is

VSWR = (1+(10^21/20)) / (1-(10^21/20))

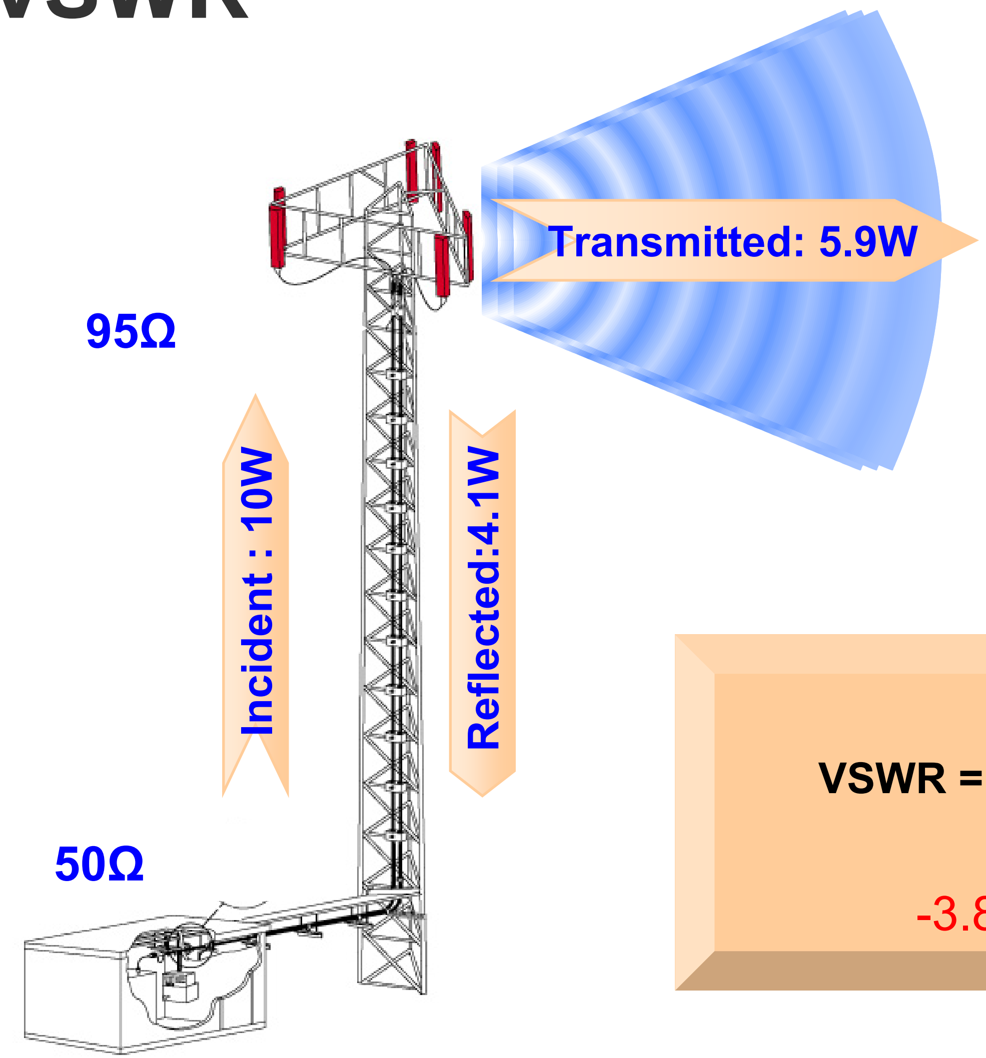
Or

-21dB RL = 1.195:1 VSWR **PASS!**

VSWR


VSWR
Test Site
M1: 1.155 @ 1887.40 MHz
M2: 1.195 @ 1964.40 MHz
VSWR
10
9
8
7
6
5
4
3
2
1
0
M1
M2
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Frequency (1885.0 - 1990.0 MHz)
CAL: ON(COAX)
CW: ON

VSWR



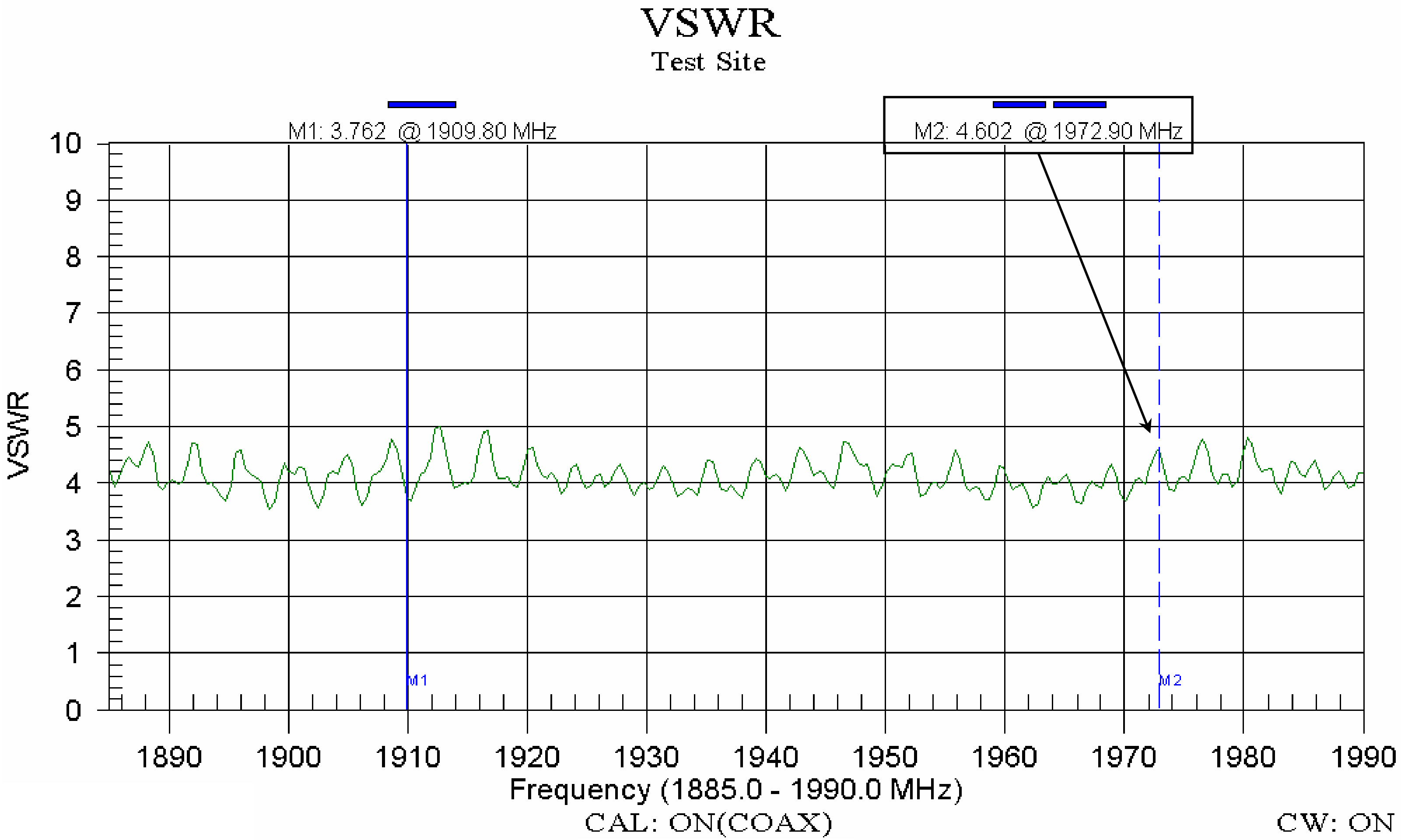
Here the VSWR is

VSWR = (1+(10^3.8/20)) / (1-(10^3.8/20))

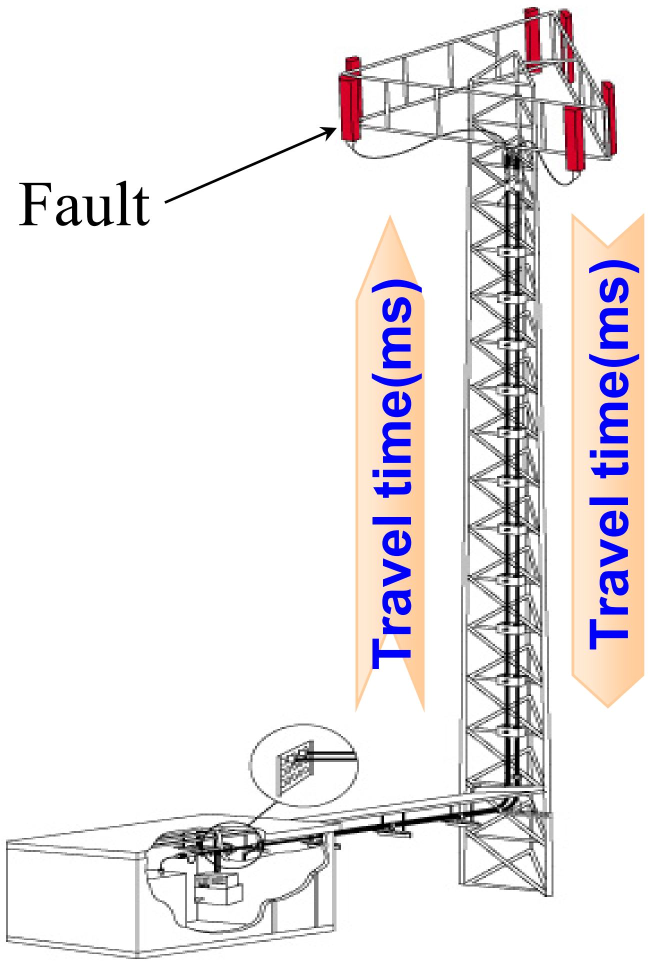
or

-3.84 dB RL = 4.60:1 VSWR **FAIL!**

VSWR


VSWR
Test Site
M1: 3.762 @ 1909.80 MHz
M2: 4.602 @ 1972.90 MHz
10
9
8
7
6
5
4
3
2
1
0
VSWR
M1
M2
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Frequency (1885.0 - 1990.0 MHz)
CAL: ON(COAX)
CW: ON

DTF

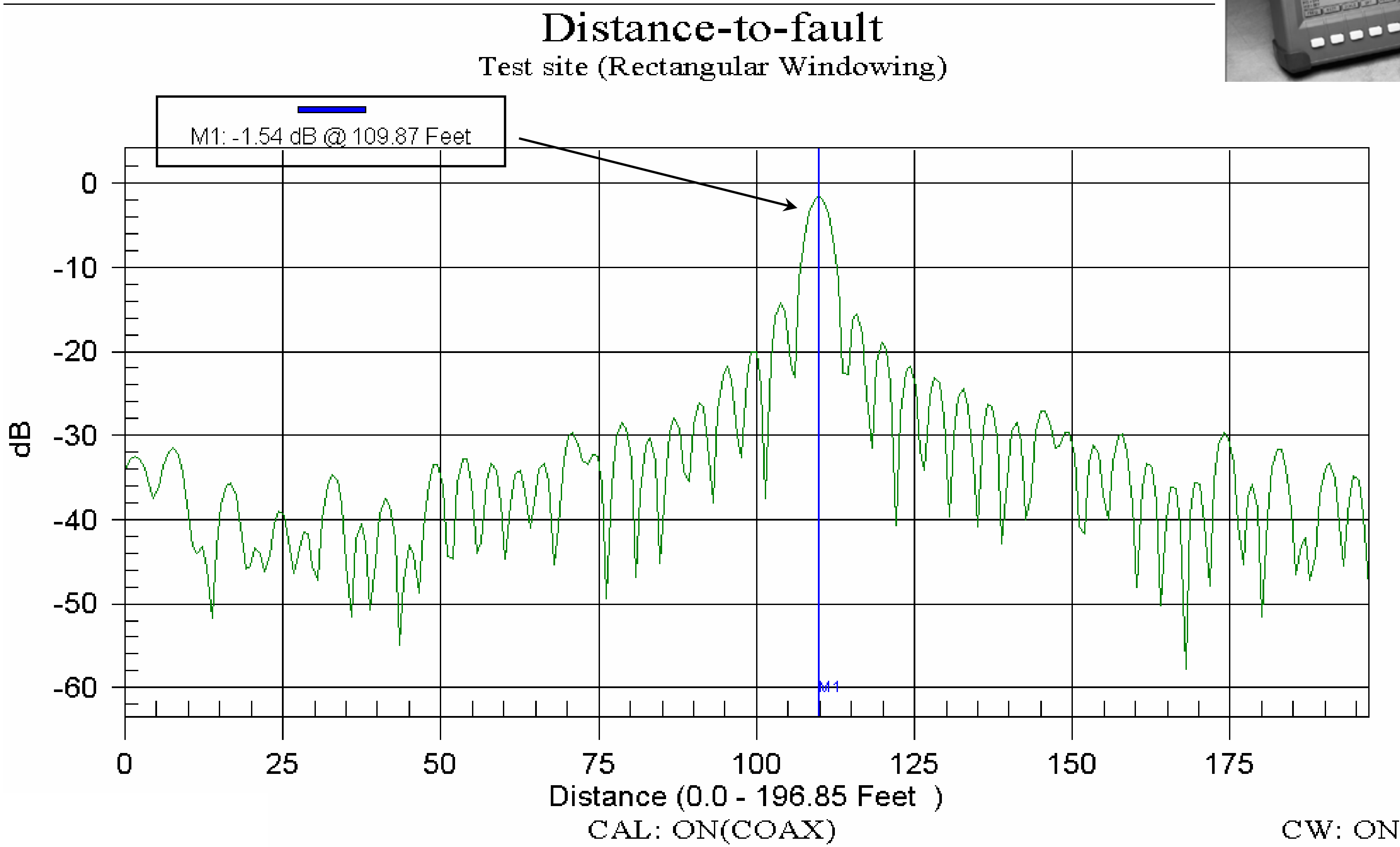


These tests work best when used as a references.

Test results may be swayed by variables such as vector addition and subtraction of phase, interfering signals and cable lengths.

Consider matching current test results to previously recorded tests and look for changes.

DTF


Distance-to-fault
Test site (Rectangular Windowing)
M1: -1.54 dB @ 109.87 Feet
dB
0
-10
-20
-30
-40
-50
-60
M1
0
25
50
75
100
125
150
175
Distance (0.0 - 196.85 Feet)
CAL: ON(COAX)
CW: ON

Effect of VSWR

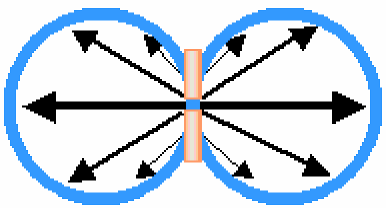
Good VSWR is only one component of an efficient antenna system.

Note: 2 dB in Return Loss is much smaller than 2 dB of forward gain!

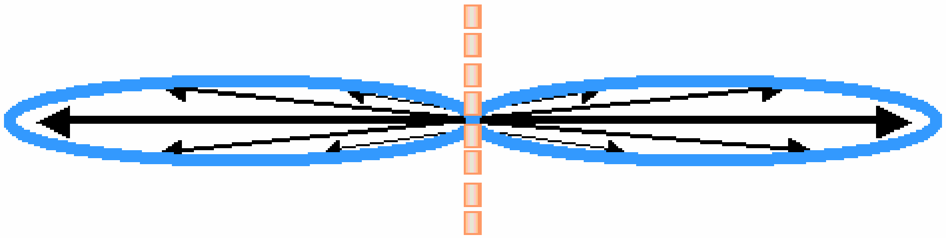
VSWR	Return Loss (dB)	Transmission Loss (dB)	Power Reflected (%)	Power Trans. (%)
1.00	$-\infty$	0.00	0.0	100.0
1.10	–26.4	0.01	0.2	99.8
1.20	–20.8	0.04	0.8	99.2
1.30	–17.7	0.08	1.7	98.3
1.40	–15.6	0.12	2.8	97.2
1.50	–14.0	0.18	4.0	96.0
2.00	–9.5	0.51	11.1	88.9

Controlling where radio energy goes.. “flattening the doughnut”

- Dipoles are combined in an array

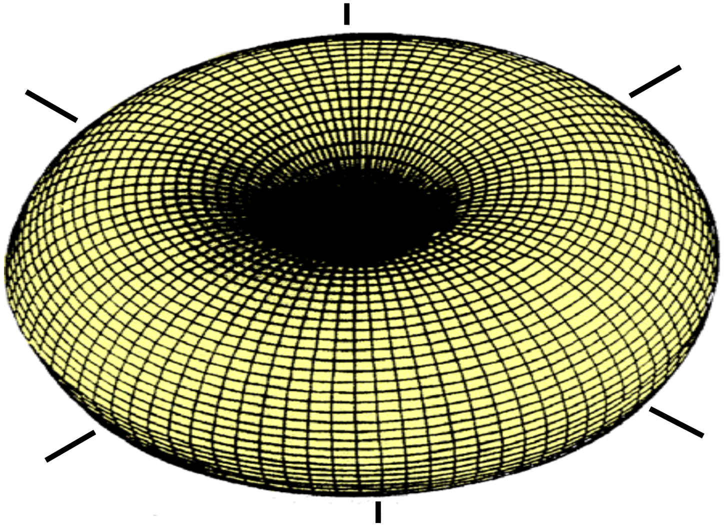


One dipole



Several dipoles in an array

3D View
Antenna Pattern

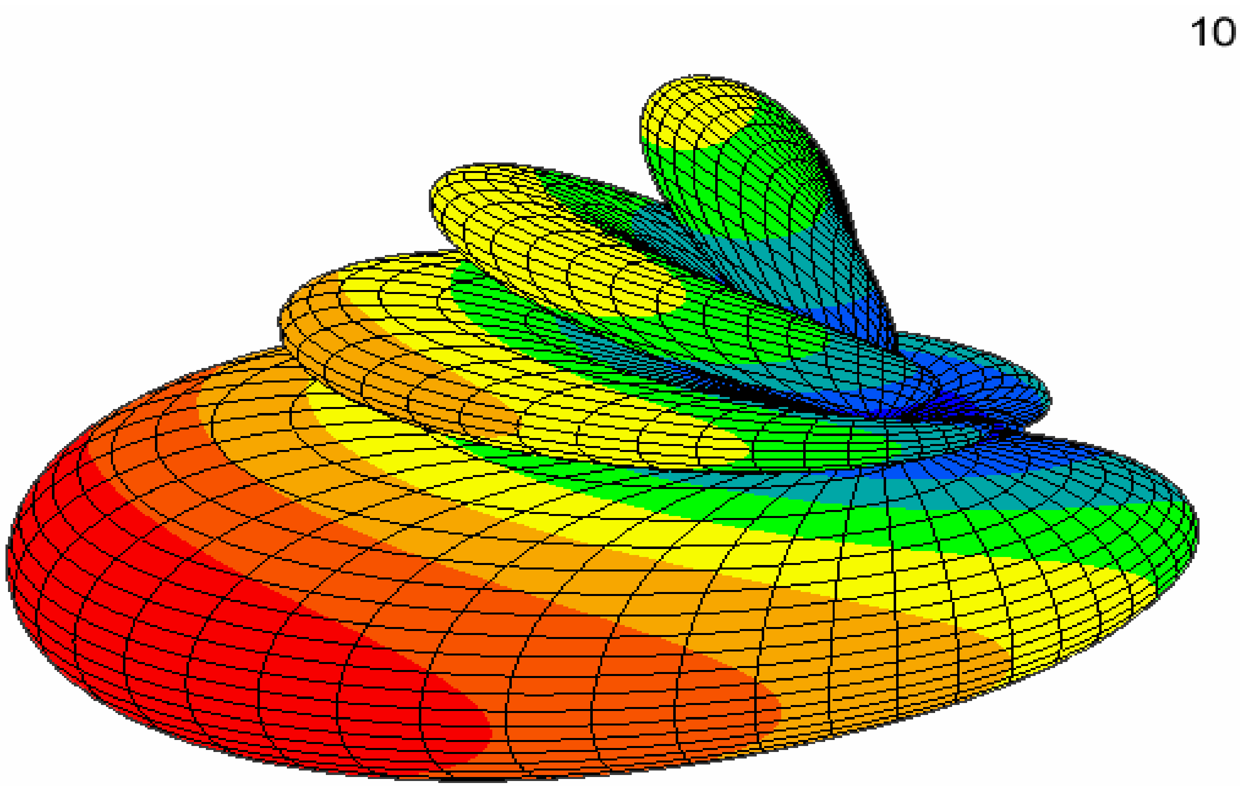


Source: COMSEARCH

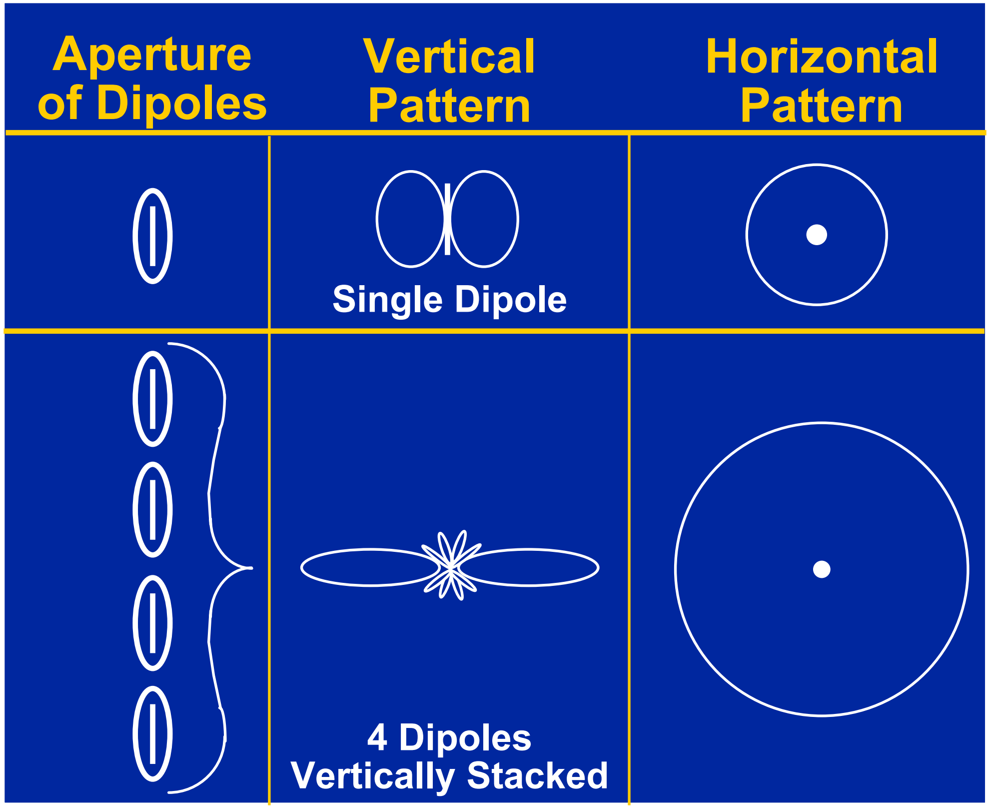
Shaping Antenna Patterns

Vertical arrangement of properly phased dipoles allows control of radiation patterns at the horizon as well as above and below the horizon.

The more dipoles are stacked vertically, the flatter the "beam" is and the higher the antenna coverage or "gain" in the general direction of the horizon.



Shaping Antenna Patterns *(cont . . .)*



Stacking 4 dipoles vertically in line changes the pattern shape (squashes the doughnut) and increases the gain over single dipole.

The peak of the horizontal or vertical pattern measures the gain.

The little lobes, illustrated in the lower section, are secondary minor lobes.

GENERAL STACKING RULE:

- Collinear elements (in-line vertically).
- Optimum spacing (for non-electrical tilt) is approximately 0.9λ.
- Doubling the number of elements increases gain by 3 dB, and reduces vertical beamwidth by half.

Gain

What is it?

Antenna gain is a comparison of the power/field characteristics of a device under test (DUT) to a specified gain standard.

Why is it useful?

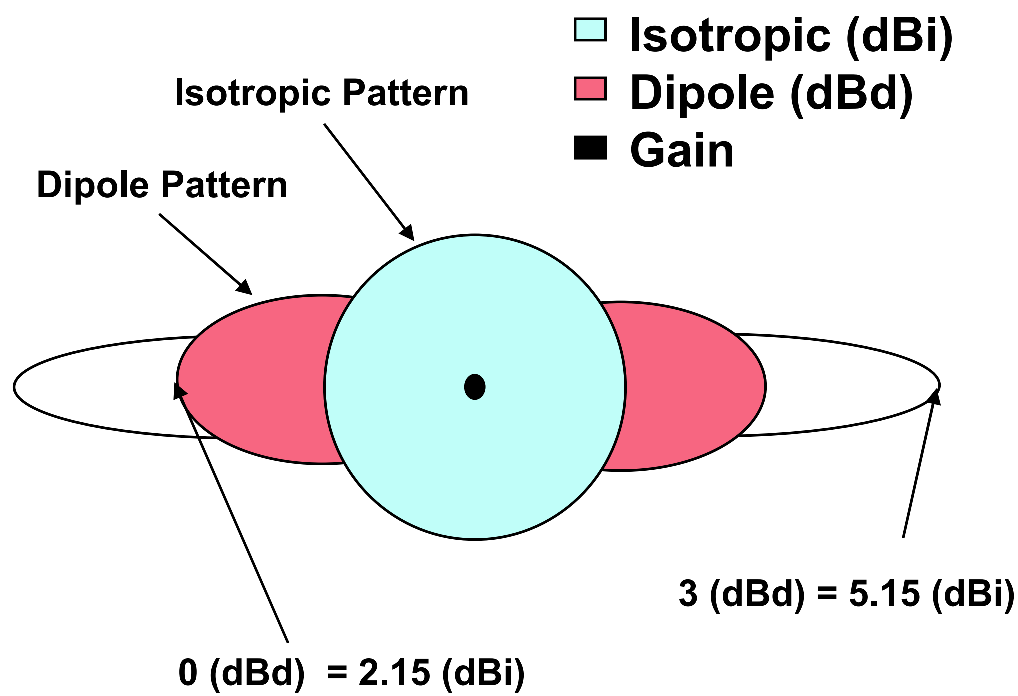
Gain is directly associated with link budget: coverage distance and/or obstacle penetration (buildings, foliage, etc).

How is it measured?

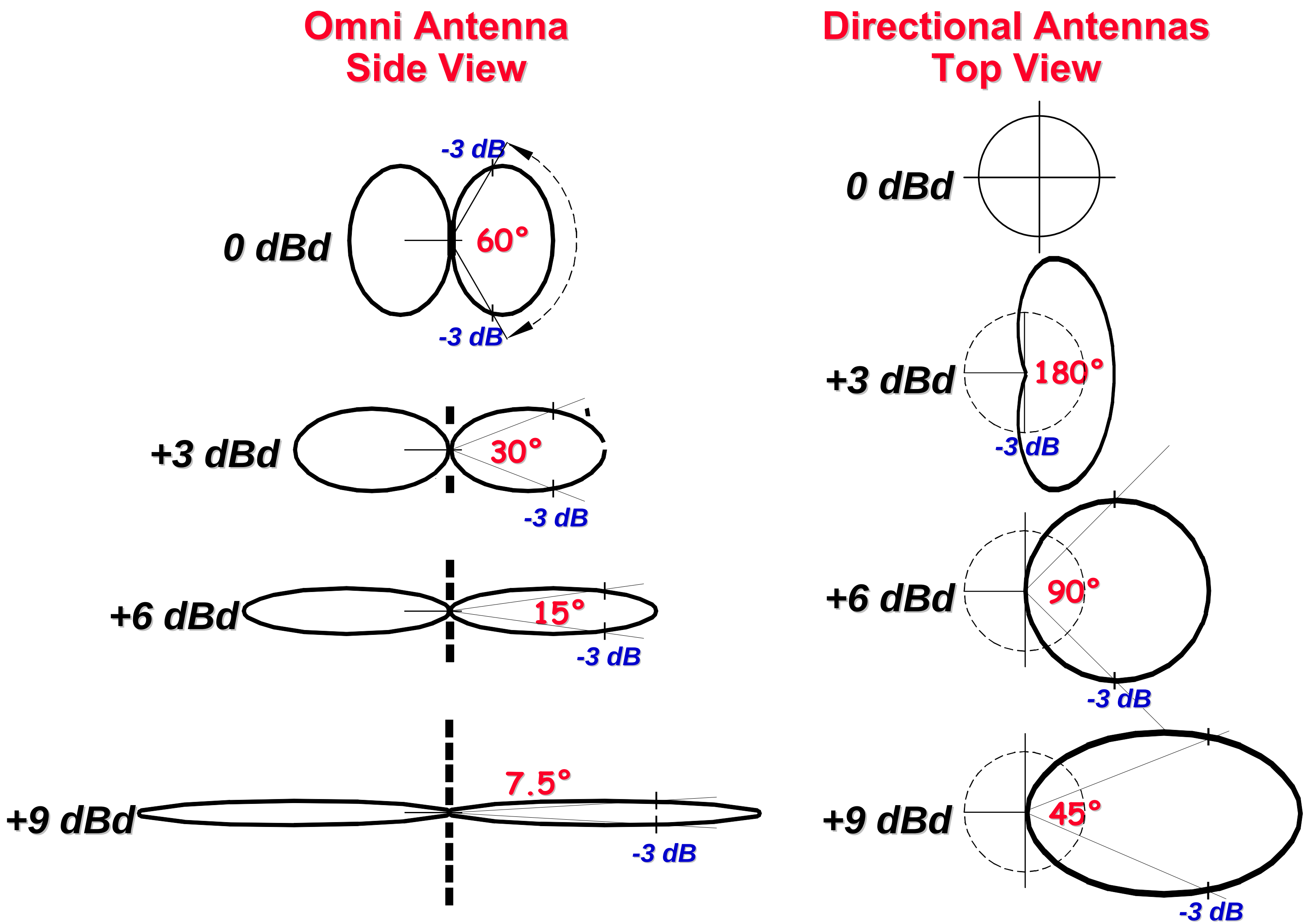
It is measured using data collected from antenna range testing. The reference gain standard must always be specified.

Gain References (dBd and dBi)

- An isotropic antenna is a single point in space radiating in a perfect sphere (not physically possible)
- A dipole antenna is one radiating element (physically possible)
- A gain antenna is two or more radiating elements phased together



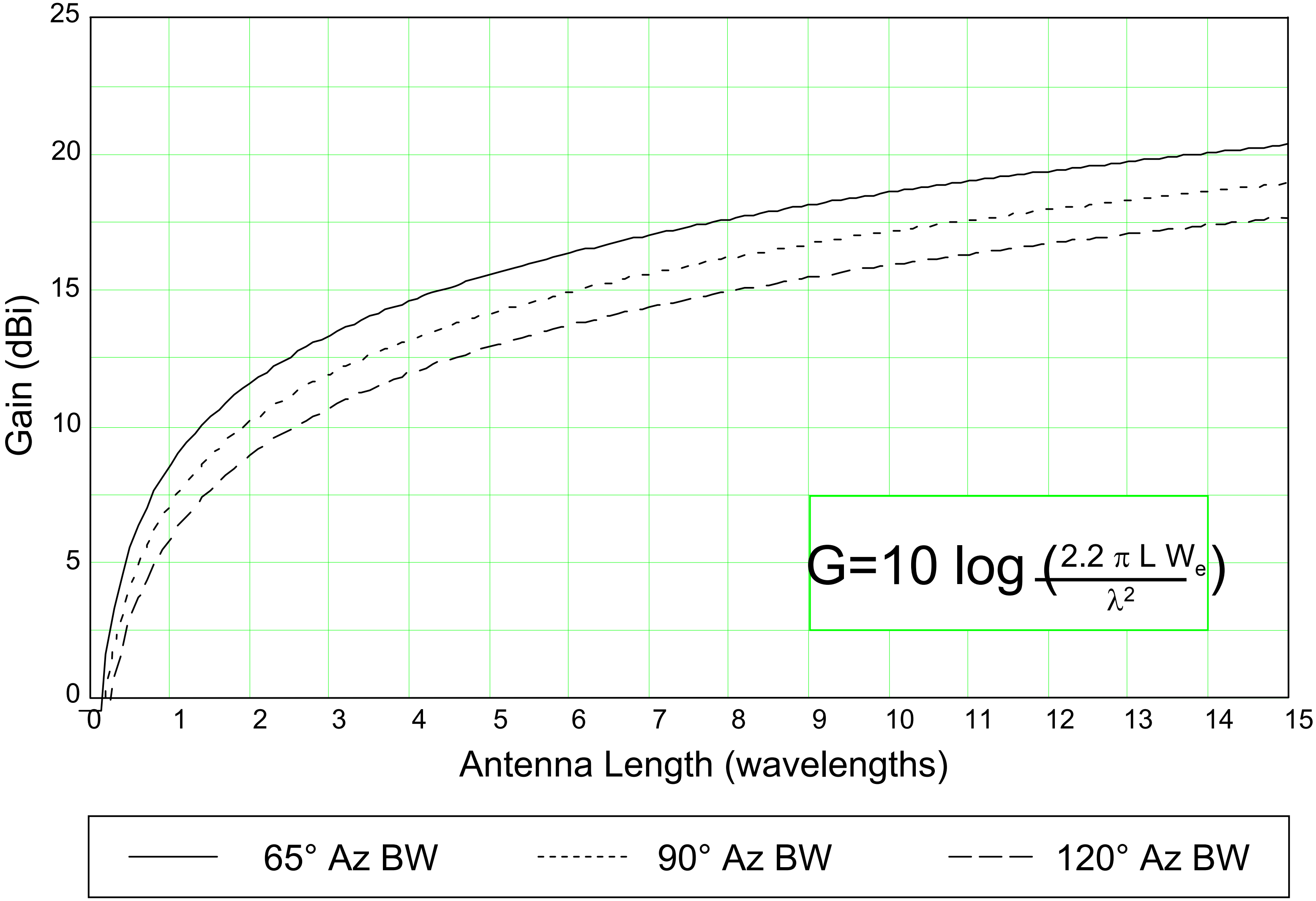
Principles of Antenna Gain



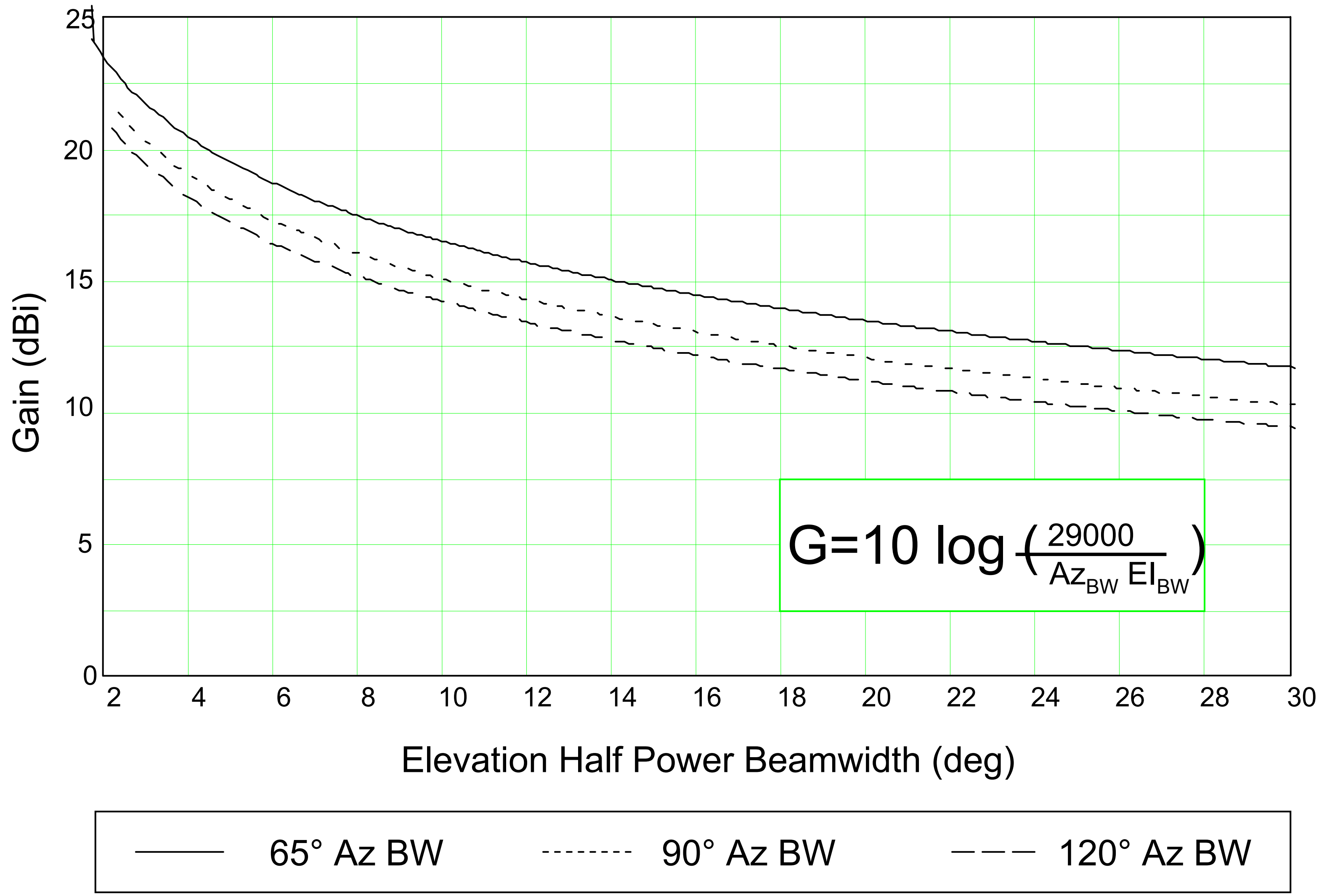
Theoretical Gain of Antennas (dBd)

# of Radiators vertically spaced (0.9λ)	Half Power Azimuth Beam Width (Influenced by Grounded Back "Plate")								Typical Length of Antenna (ft.)		
	360°	180°	120°	105°	90°	60°	45°	33°	800/900 MHzPCS	DCS 1800 1900	Vertical Beamwidth
1	0	3	4	5	6	8	9	10.5	1'	0.5'	60°
2	3	6	7	8	9	11	12	13.6	2'	1'	30°
3	4.5	7.5	8.5	9.5	10.5	12.5	13.5	15.1	3'	1.5'	20°
4	6	9	10	11	12	14	15	16.6	4'	2'	15°
6	7.5	10.5	11.5	12.5	13.5	15.5	16.5	18.1	6'	3'	10°
8	9	12	13	14	15	17	18	19.6	8'	4'	7.5°

Gain vs. Length



Gain vs. Beamwidths



Antenna Gain

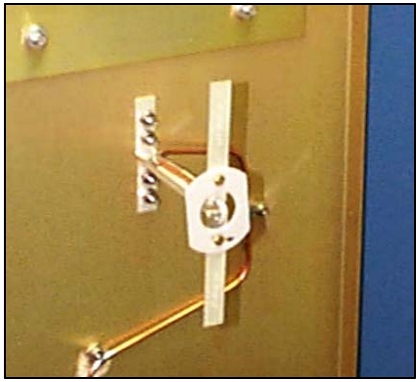
- Gain (dBi) = Directivity (dBi) – Losses (dB)
- Losses: Conductor
  Dielectric
  Impedance
  Polarization
- Measure Using ‘Gain by Comparison’

Polarization

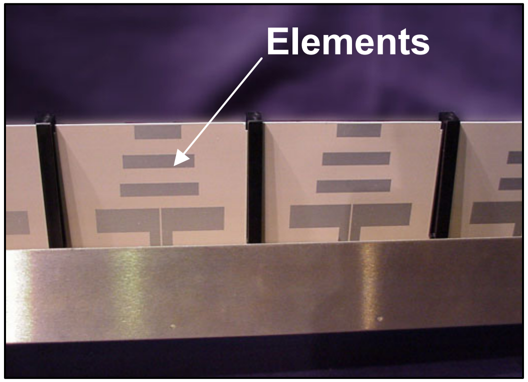
- Electric and magnetic fields are interdependent => Electromagnetic wave
- Time-changing electric field generates magnetic field, vice versa
- An antenna's polarization is a characteristic of the EM wave, i.e. electric field's orientation
- If antenna and incoming EM wave are co-polarized => Max response from antenna

BREAK

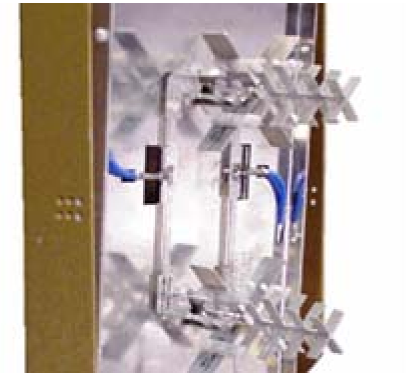
Various Radiator Designs



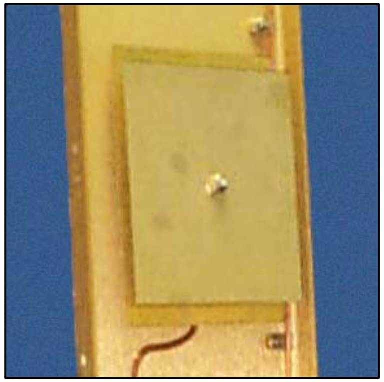
Dipole



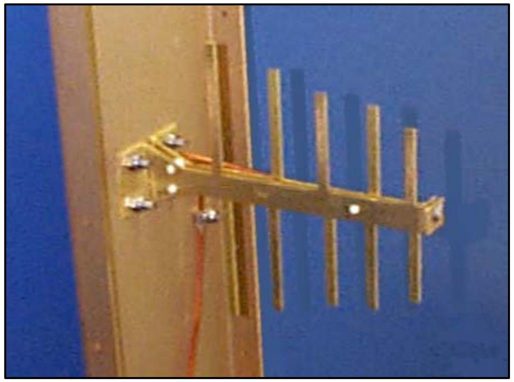
1800/1900/UMTS
Directed Dipole™



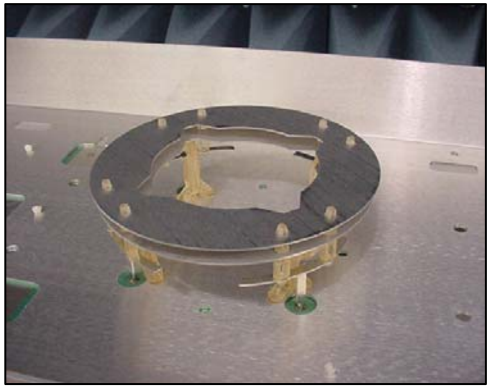
Diversity (Dual-Pol)
Directed Dipole™



Patch

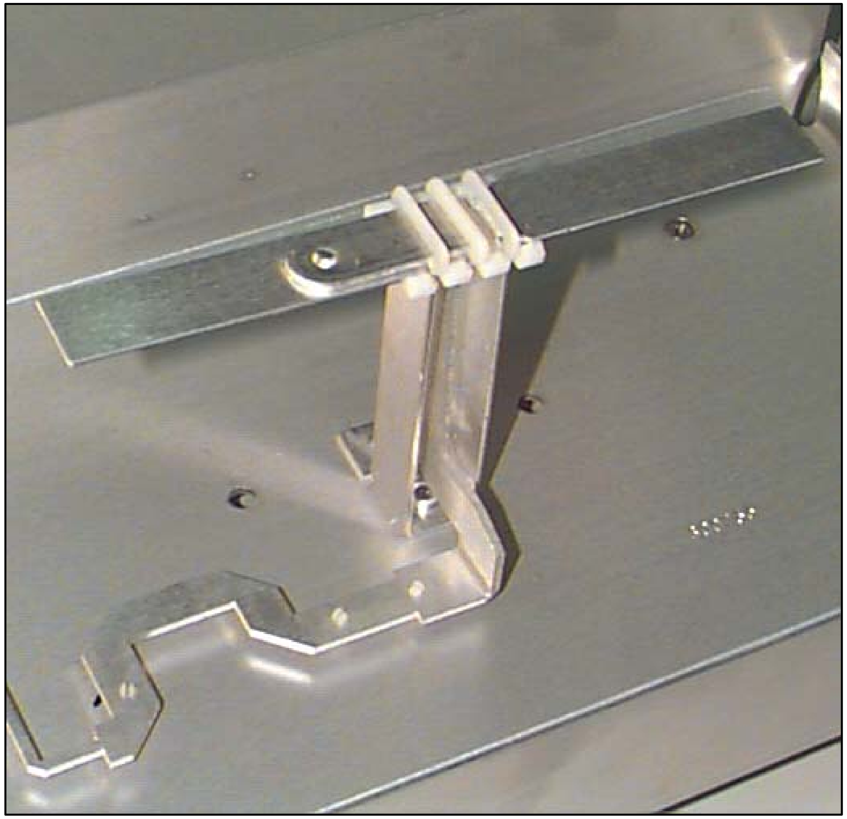


800/900 MHz
Directed Dipole™



MAR
Microstrip Annular Ring

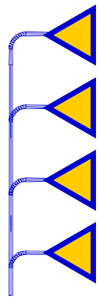
Dipoles



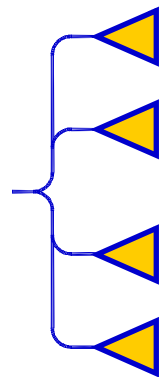
Single Dipole

Crossed Dipole

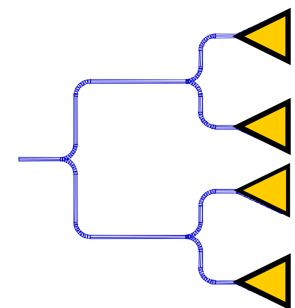
Feed Harness Construction



Series Feed

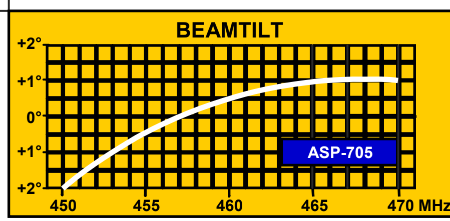


Center Feed (Hybrid)



Corporate Feed

Feed Harness Construction *(cont . . .)*

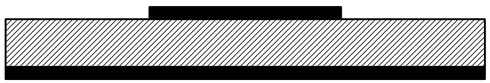
	Series Feed	Center Feed (Hybrid)	Corporate Feed
Advantages:	• Minimal feed losses • Simple feed system	• Frequency independent main lobe direction • Reasonably simple feed system	• Frequency independent main beam direction • More beam shaping ability, side lobe suppression
Disadvantages:		• Not as versatile as corporate (less bandwidth, less beam shaping)	• Complex feed system

Feed Networks

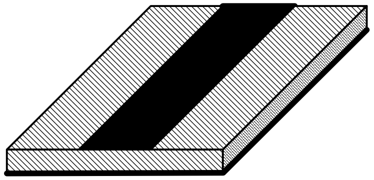
- Cable
- Microstripline, Corporate Feeds
  - Dielectric Substrate
  - Air Substrate
- T-Line Feed and Radiator

Microstrip Feed Lines

- Dielectric Substrate
  - uses ‘printed circuit’ technology
  - power limitations
  - dielectric substrate causes loss (1.0 dB/m)



- Air Substrate
  - metal strip spaced above a groundplane
  - minimal solder or welded joints
  - laser cut or punched
  - air substrate cause minimal loss (0.5 dB/m)



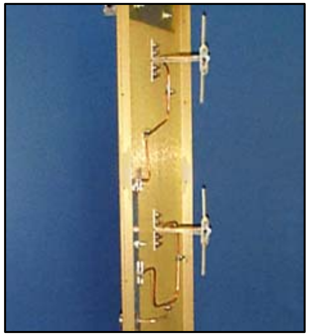
Air Microstrip Network

Dielectric Substrate Microstrip

Stacking Dipoles

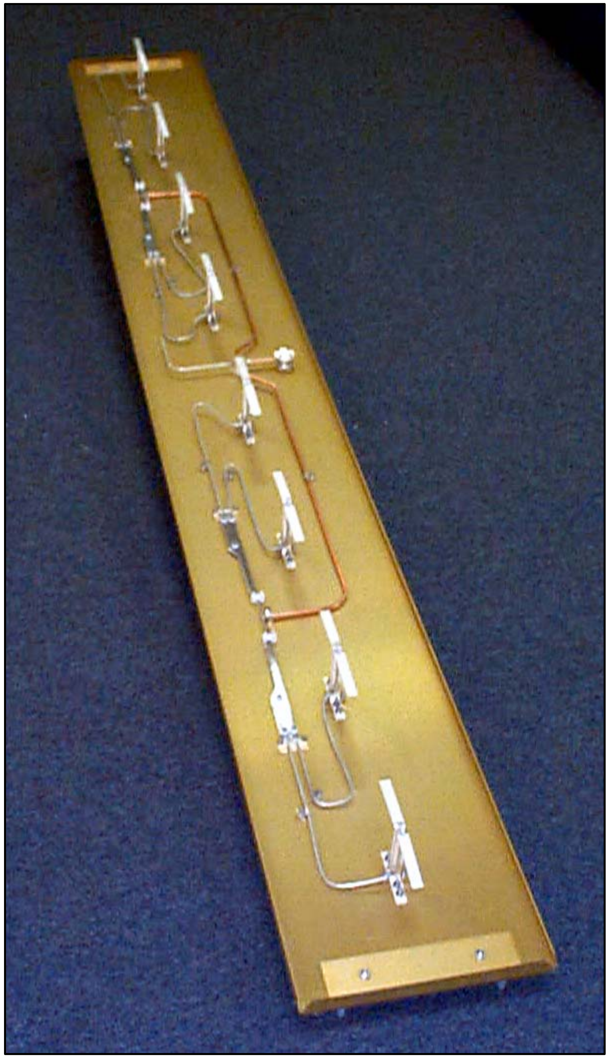
1 Dipole

2 Dipoles



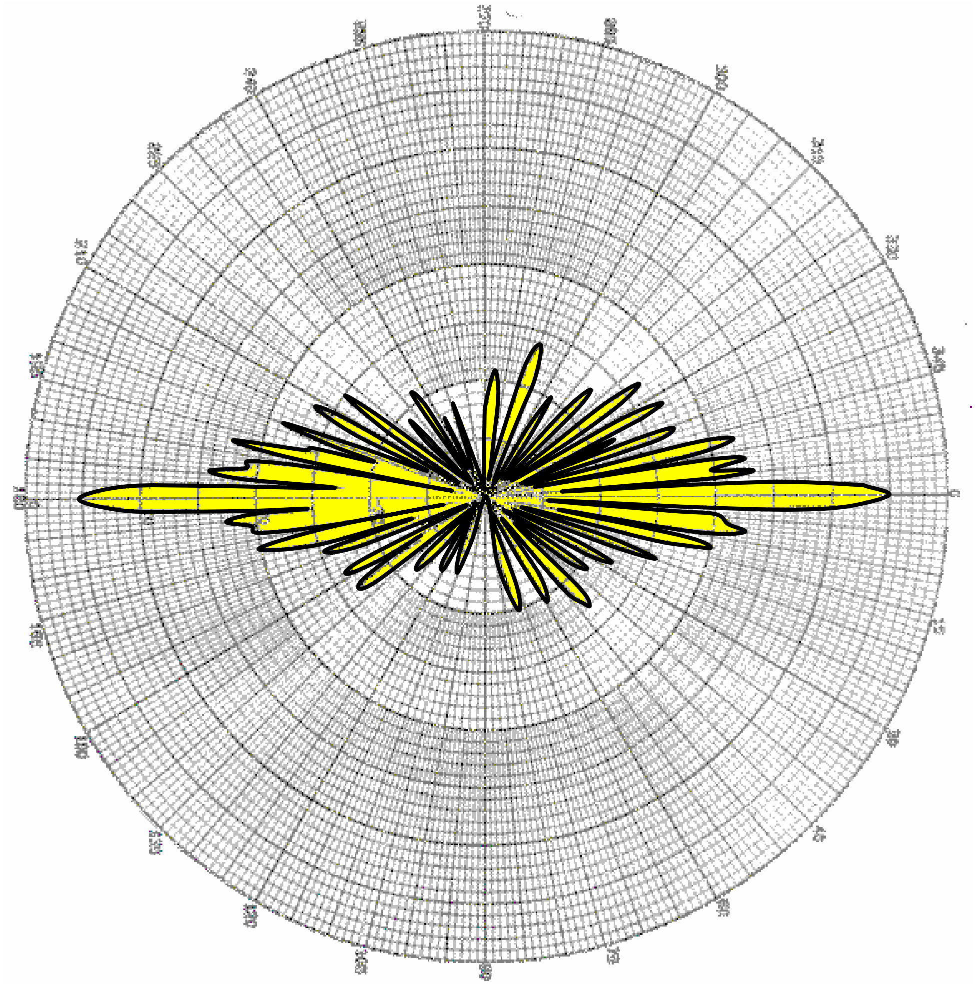
4 Dipoles

8 Dipoles

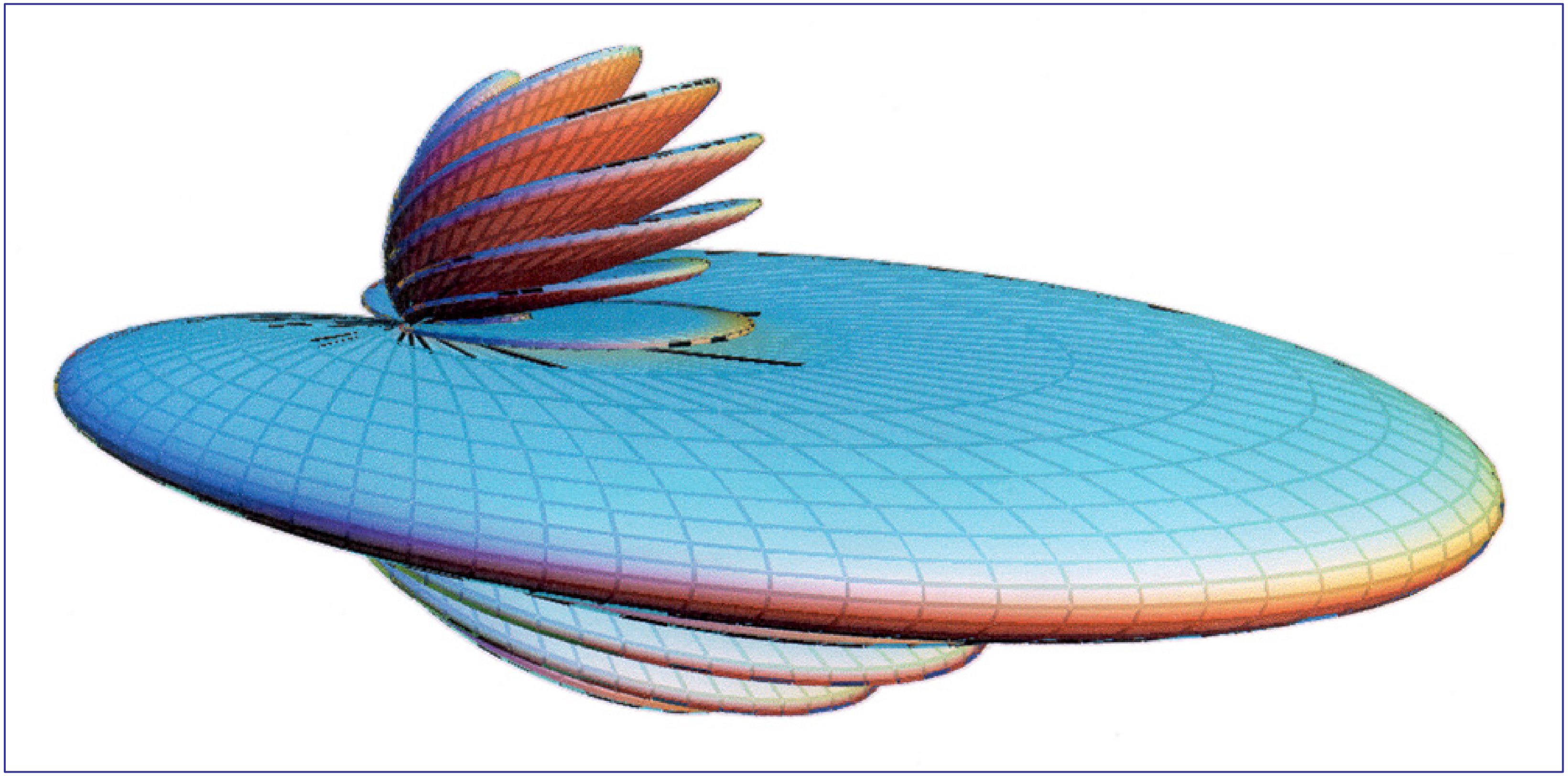


Azimuth Omni Antenna

Vertical Pattern



Directional Array Antenna
Pattern Simulation



Main Lobe

What is it?

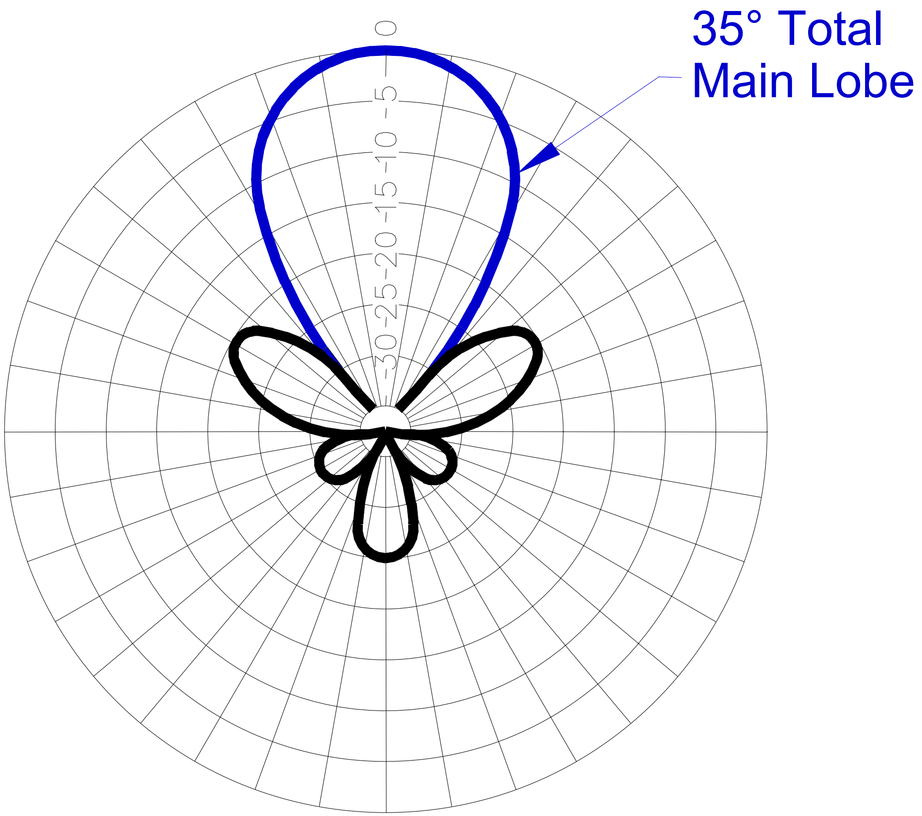
The main lobe is the radiation pattern lobe that contains the majority portion of radiated energy.

Why is it useful?

Shaping of the pattern allows the contained coverage necessary for interference-limited system designs.

How is it measured?

The main lobe is characterized using a number of the measurements which will follow.



Half-Power Beamwidth
Horizontal and Vertical

What is it?

The angular span between the half-power (-3 dB) points measured on the cut of the antenna's main lobe radiation pattern.

Why is it useful?

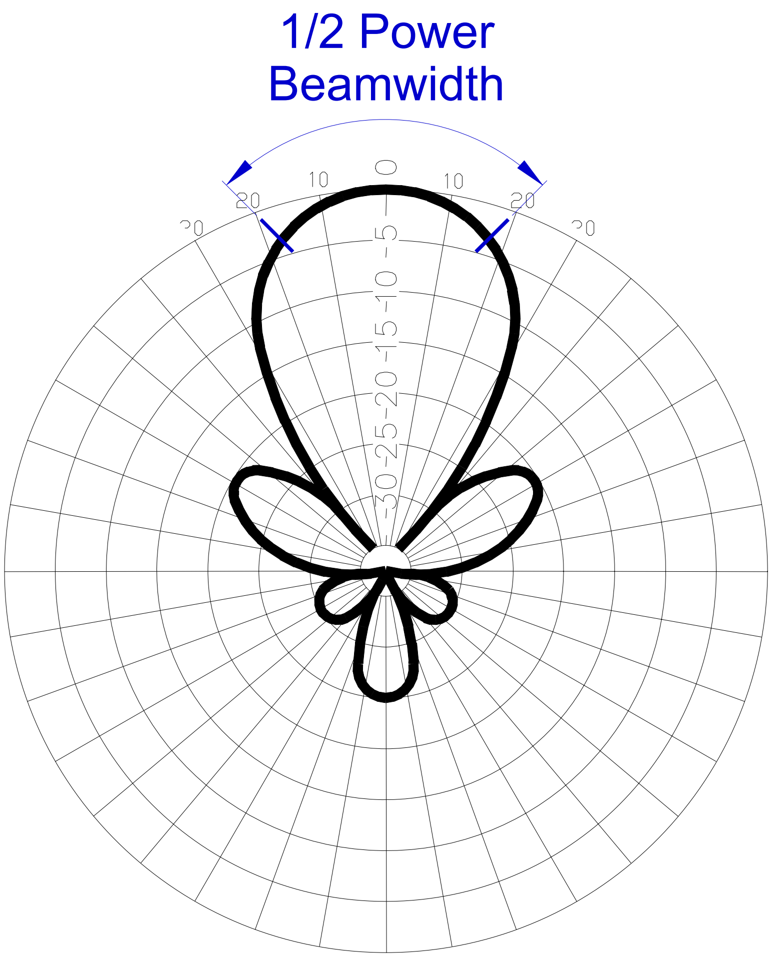
It allows system designers to choose the optimum characteristics for coverage vs. interference requirements.

How is it measured?

It is measured using data collected from antenna range testing.

What is T-Mobile standard?

Most applications require 65 degrees in azimuth, ~5 degrees in elevation.



Front-To-Back Ratio

What is it?

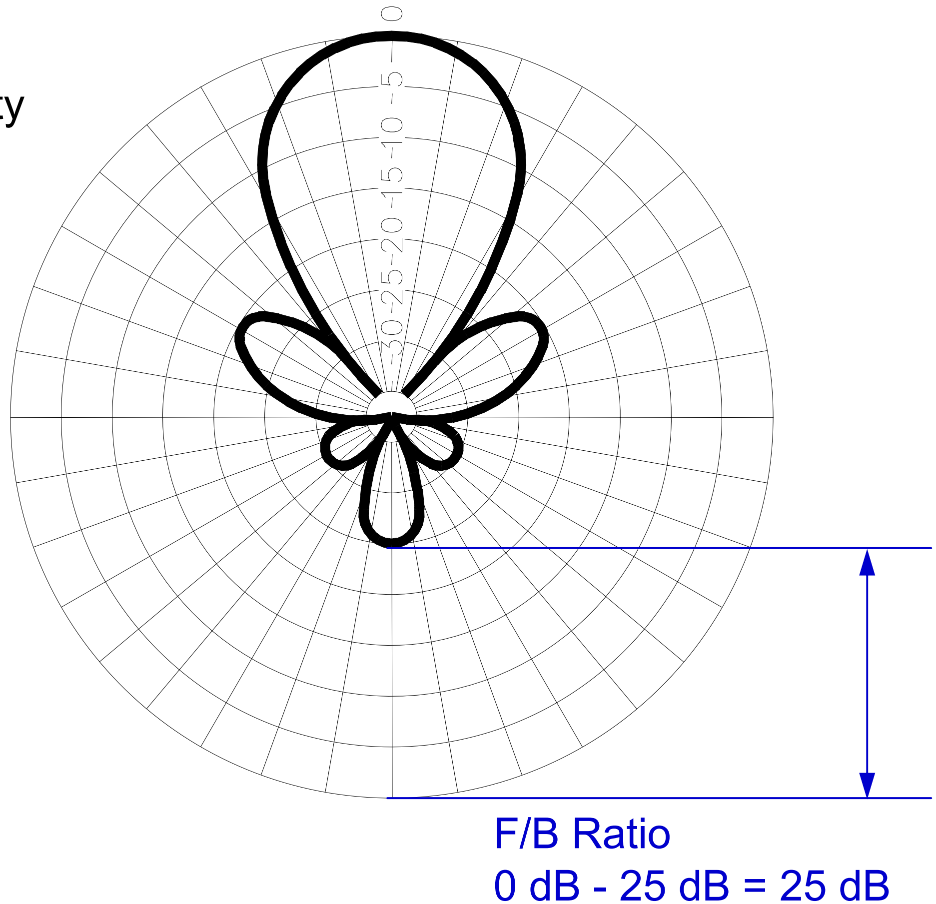
The ratio in dB of the maximum directivity of an antenna to its directivity in a specified rearward direction.

Why is it useful?

It characterizes unwanted interference on the backside of the main lobe. The larger the number, the better!

How is it measured?

It is measured using data collected from antenna range testing.



What is T-Mobile standard?

30 dB throughout the region that is +/- 45 degrees directly back of the main lobe.

Sidelobe Level

What is it?

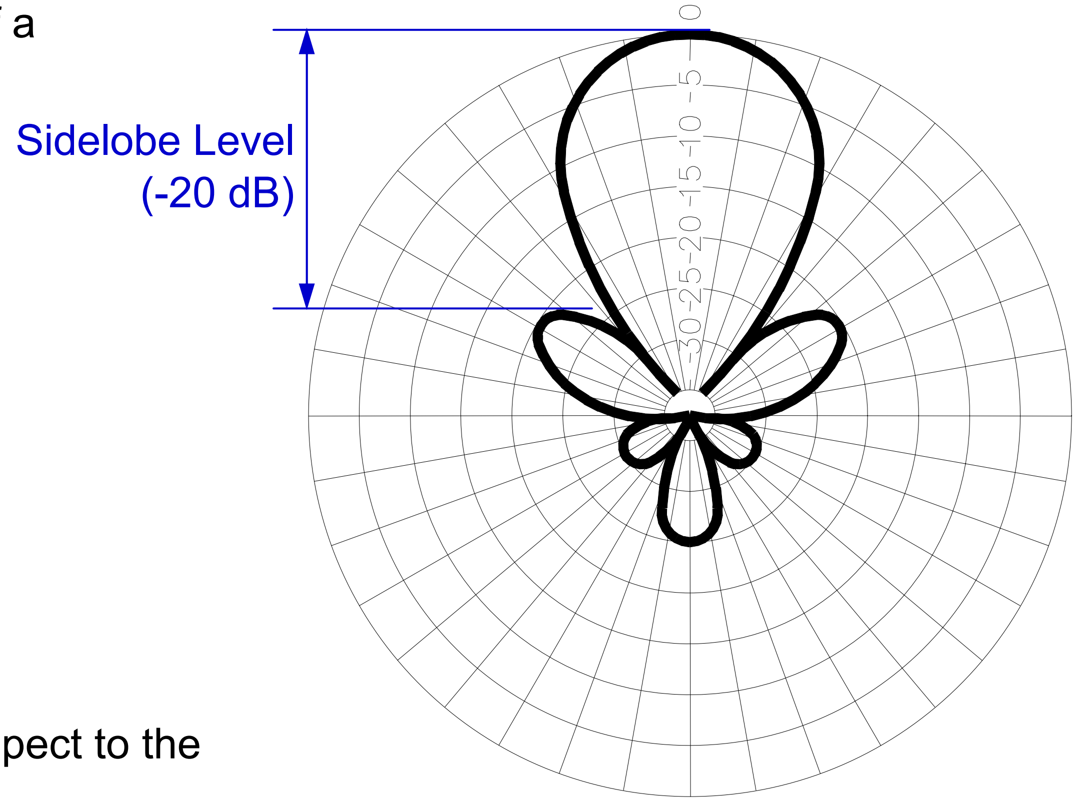
Sidelobe level is a measure of a particular sidelobe or angular group of sidelobes with respect to the main lobe.

Why is it useful?

Sidelobe level or pattern shaping allows the minor lobe energy to be tailored to the antenna's intended use. See Null Fill and Upper Sidelobe Suppression.

How is it measured?

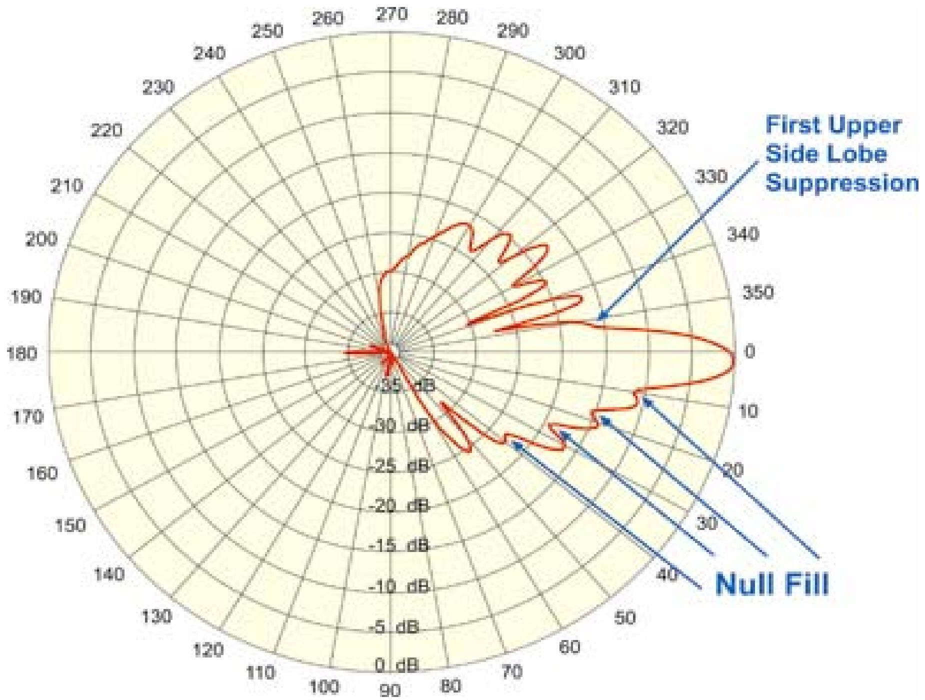
It is always measured with respect to the main lobe in dB.



Null Filling

What is it?

Null Filling is an array optimization technique that reduces the null between the lower lobes in the elevation plane.



Why is it useful?

For arrays with a narrow vertical beam-width (less than 12°), null filling significantly improves signal intensity in all coverage targets below the main lobe.

How is it measured?

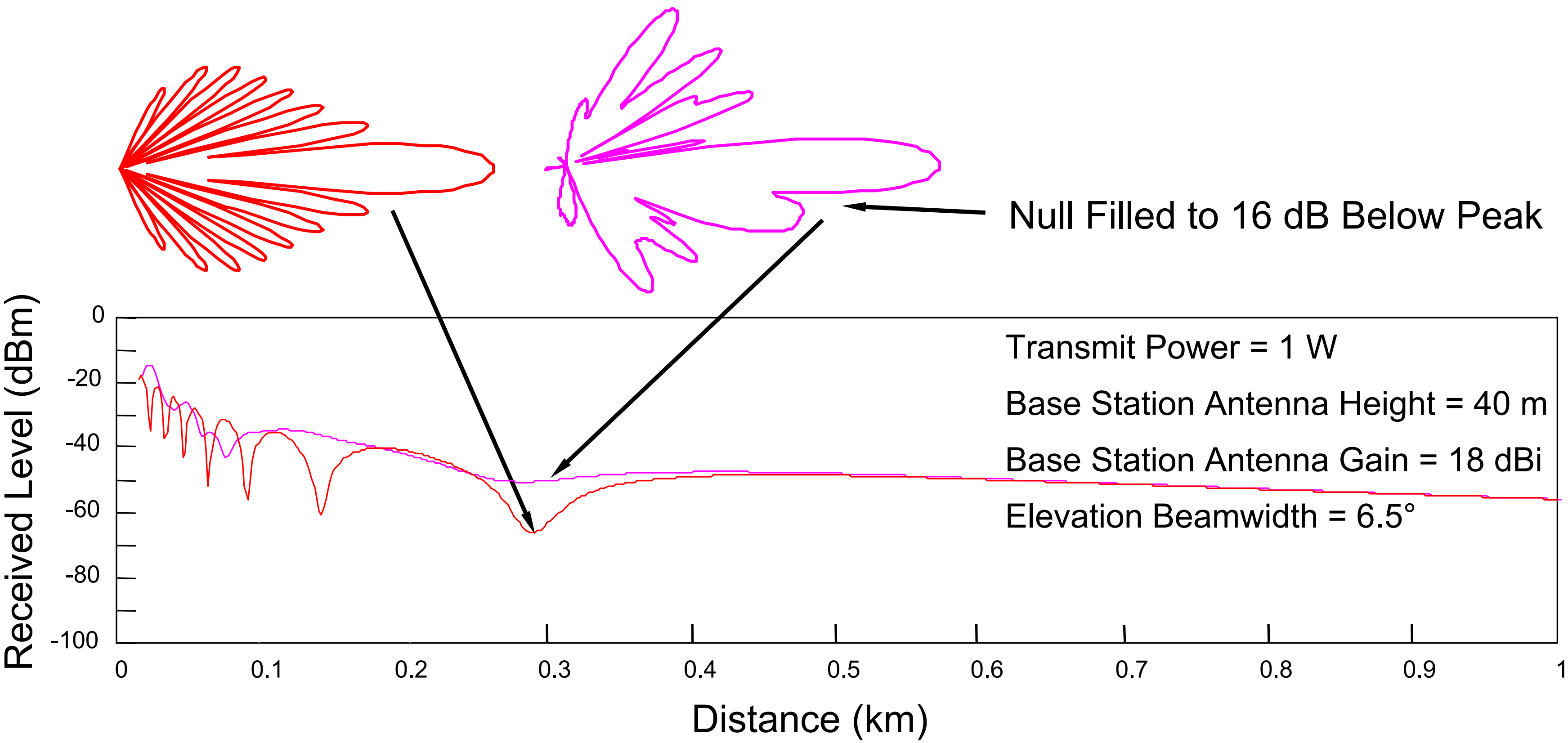
Null fill is easiest explained as the relative dB difference between the peak of the main beam and the depth of the 1st lower null.

What is T-Mobile standard?

The depth of the 1st lower null shall not be more than 20 dB relative to the peak of the main beam.

Null Fill

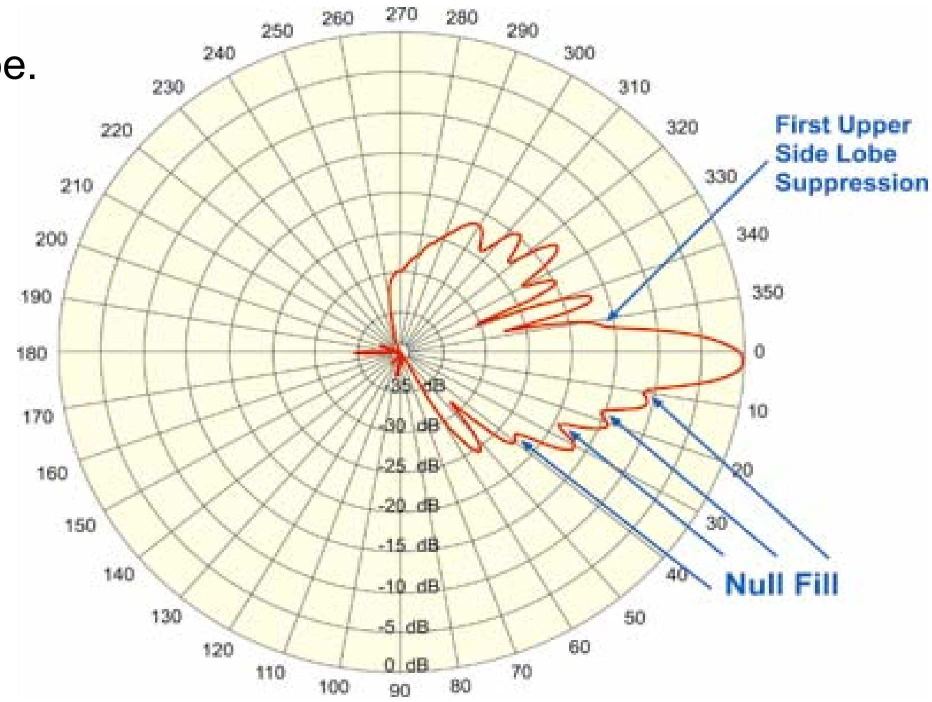
Important for antennas with narrow elevation beamwidths.



Upper Sidelobe Suppression

What is it?

Upper sidelobe suppression (USLS) is an array optimization technique that reduces the undesirable sidelobes above the main lobe.



Why is it useful?

For arrays with a narrow vertical beamwidth (less than 12°), USLS can significantly reduce interference due to multi-path or when the antenna is mechanically downtilted.

How is it measured?

USLS is the relative dB difference between the peak of the main beam peak of the first upper sidelobe.

What is T-Mobile standard?

Upper side lobes must be at least –18 dB from the main lobe through zenith.

Orthogonality

What is it?

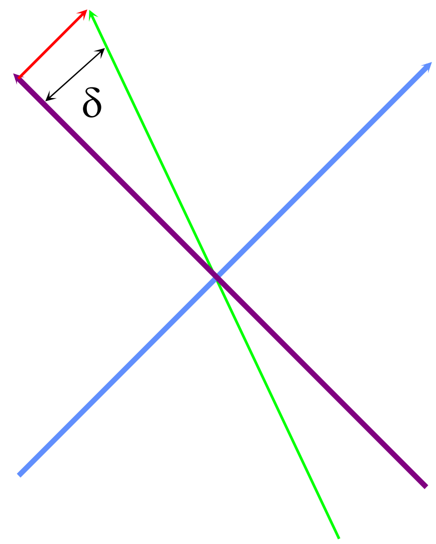
The ability of an antenna to discriminate between two EM waves whose polarization difference is 90 degrees.

Why is it useful?

Orthogonal arrays within a single antenna allow for polarization diversity. (As opposed to spatial diversity.)

How is it measured?

The difference between the co-polar pattern and the cross-polar pattern, usually measured in the boresite (the direction of the main signal).



XPol = 20 log (tan (δ))

δ = 0°, XPol = -∞ dB
δ = 5°, XPol = -21 dB
δ =10°, XPol = -15 dB
δ =15°, XPol = -11 dB
δ =20°, XPol = -9 dB
δ =30°, XPol = -5 dB
δ =40°, XPol =-1.5 dB

Cross-Pol Ratio (CPR)

What is it?

CPR is a comparison of the co-pol vs. cross-pol pattern performance of a dual-polarized antenna generally over the sector of interest (alternatively over the 3 dB beamwidth).

Why is it useful?

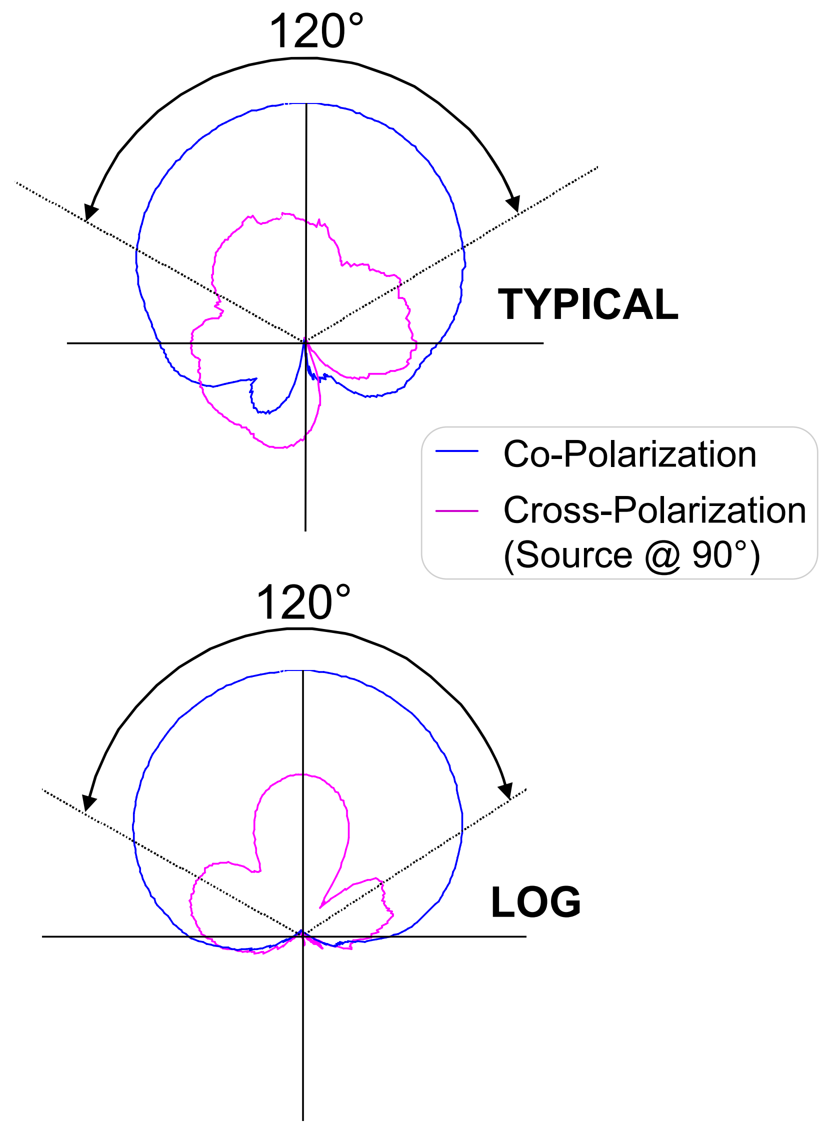
It is a measure of the ability of a dual-pol array to distinguish between orthogonal EM waves. The better the CPR, the better the performance of polarization diversity.

How is it measured?

It is measured using data collected from antenna range testing and compares the two plots in dB over the specified angular range.

What is T-Mobile standard?

16 dB minimum for azimuth pattern.



Horizontal Beam Tracking

What is it?

It refers to the beam tracking between the two beams of a +/-45° polarization diversity antenna over a specified angular range.

Why is it useful?

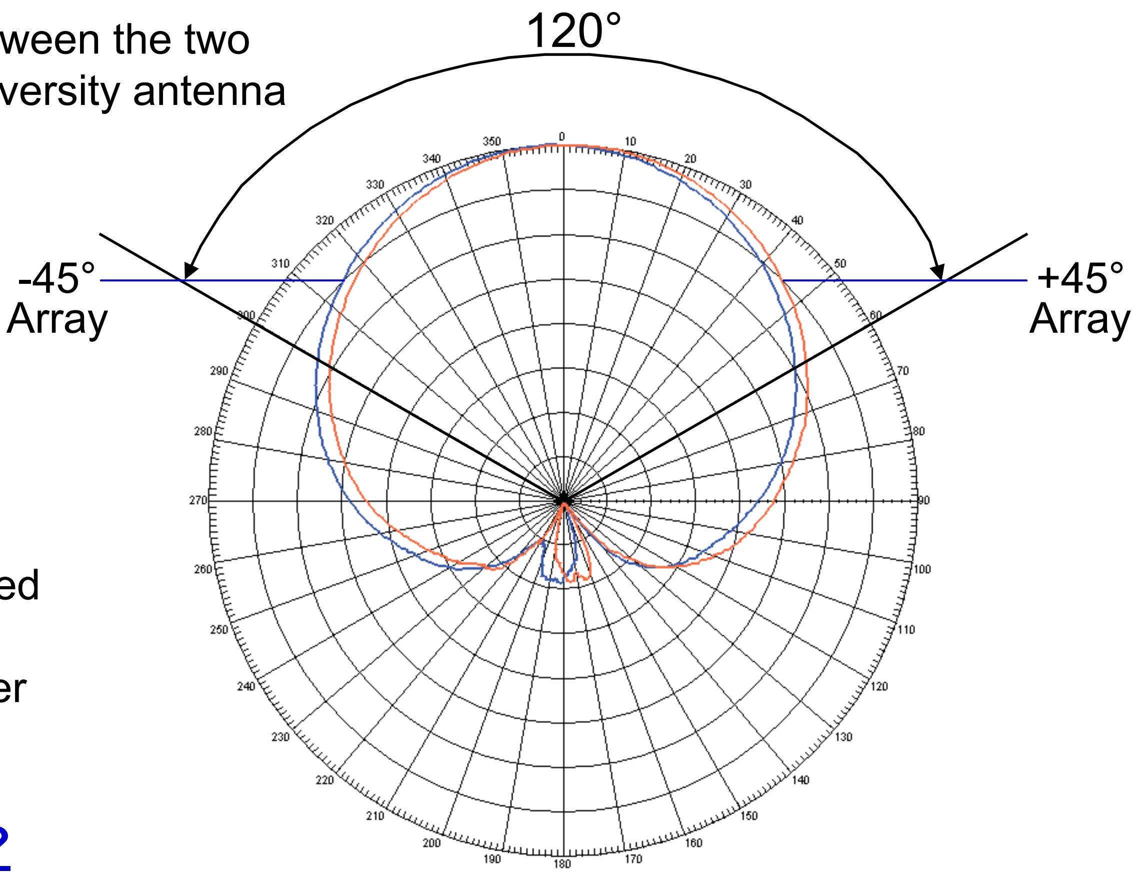
For optimum diversity performance, the beams should track as closely as possible.

How is it measured?

It is measured using data collected from antenna range testing and compares the two plots in dB over the specified angular range.

What is T-Mobile standard?

The beams shall track within 1 dB over the 3 dB horizontal beamwidth.



Beam Squint

What is it?

The amount of pointing error of a given beam referenced to mechanical boresite.

Why is it useful?

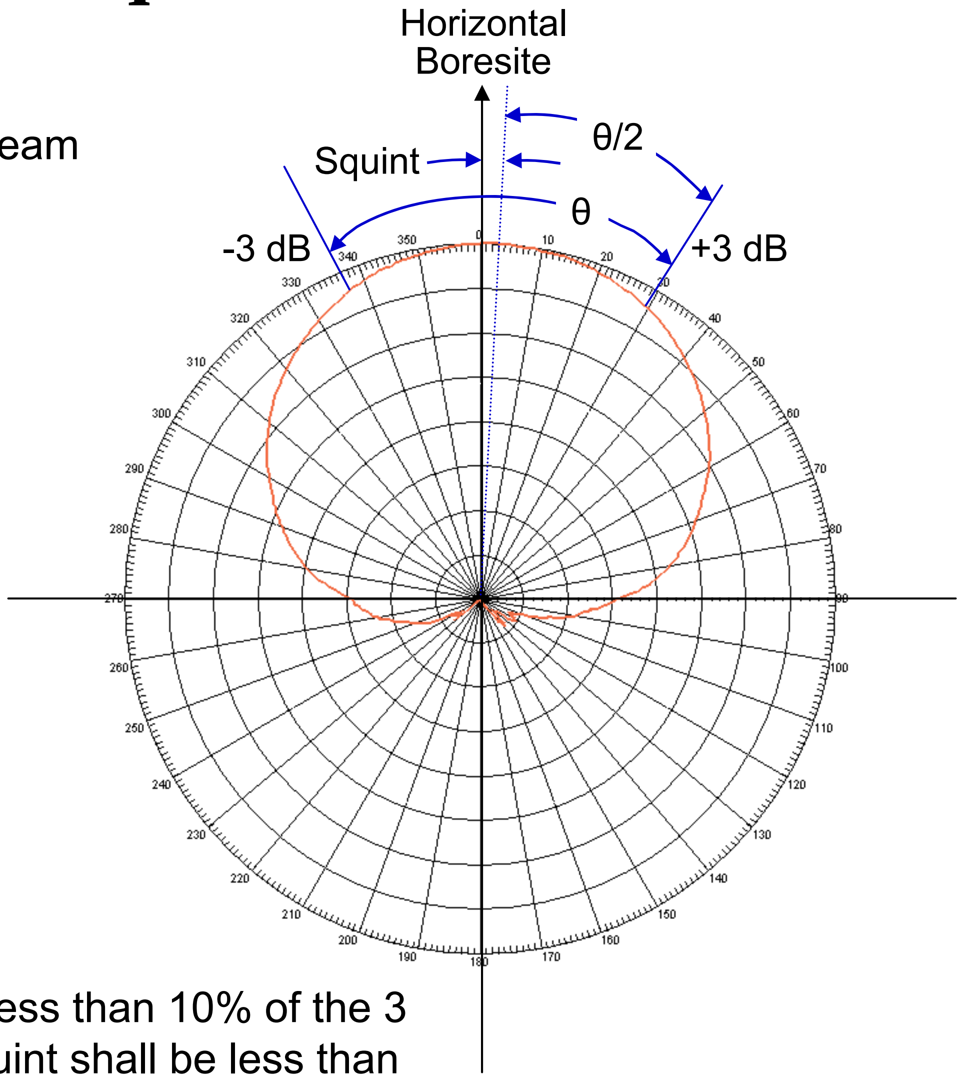
The beam squint can affect the sector coverage if it is not at mechanical boresite. It can also affect the performance of the polarization diversity style antennas if the two arrays do not have similar patterns.

How is it measured?

It is measured using data collected from antenna range testing.

What is T-Mobile standard?

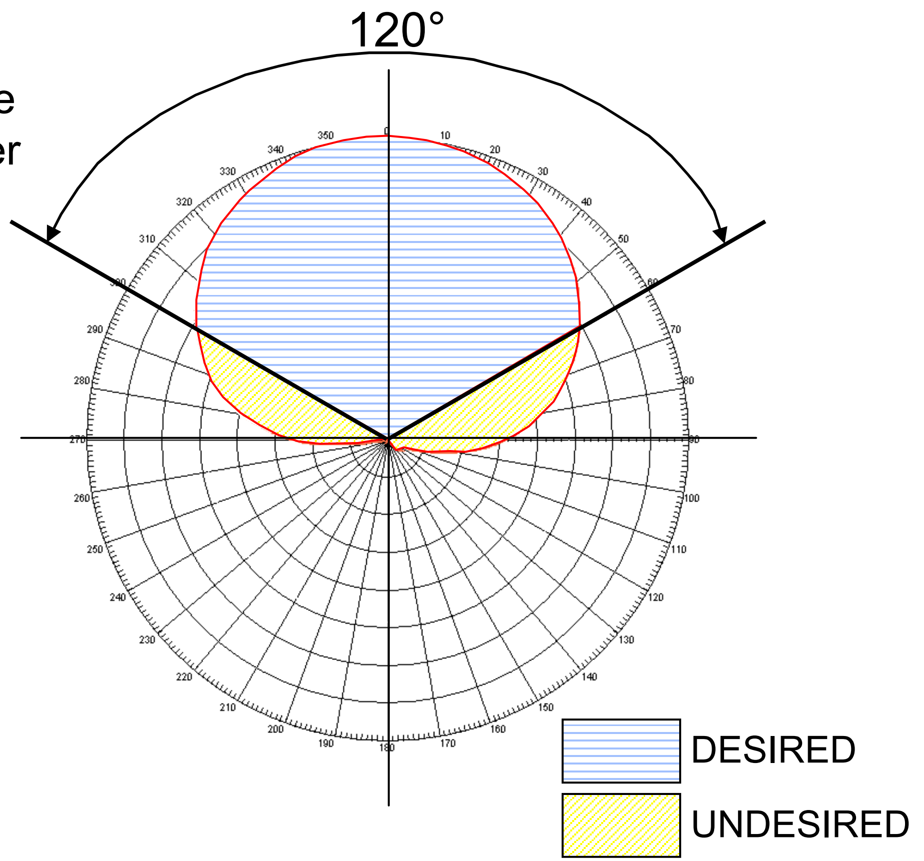
For the horizontal beam, squint shall be less than 10% of the 3 dB beamwidth. For the vertical beam, squint shall be less than 10% of the 3 dB beamwidth.



Sector Power Ratio (SPR)

What is it?

SPR is a ratio expressed in percentage of the power outside the desired sector to the power inside the desired sector created by an antenna's pattern.



Why is it useful?

It is a percentage that allows comparison of various antennas. The better the SPR, the better the interference performance of the system.

How is it measured?

It is mathematically derived from the measured range data.

$$SPR\ (\%) = \frac{\sum_{60}^{300} P_{Undesired}}{\sum_{300}^{60} P_{Desired}} \times 100$$

What is T-Mobile standard?

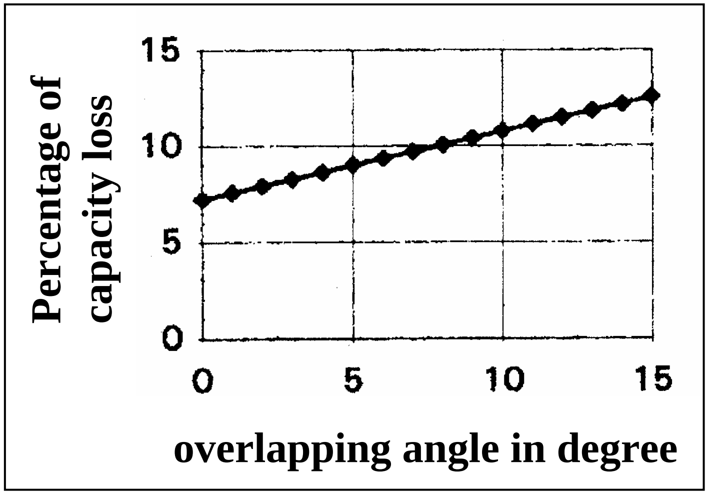
(Being studied.)

120° Sector Overlay Issues

"On the Capacity and Outage Probability of a CDMA Heirarchial Mobile System with Perfect/Imperfect Power Control and Sectorization"
By: Jie ZHOU et, al IEICE TRANS FUNDAMENTALS, VOL.E82-A, NO.7 JULY 1999

. . . From the numerical results, the user capacities are dramatically decreased as the imperfect power control increases and the overlap between the sectors (imperfect sectorization) increases . . .

"Effect of Soft and Softer Handoffs on CDMA System Capacity"
By: Chin-Chun Lee et, al IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 47, NO. 3, AUGUST 1998



Qualitatively, excessive overlay also reduces capacity of TDMA and GSM systems.

The Impact:

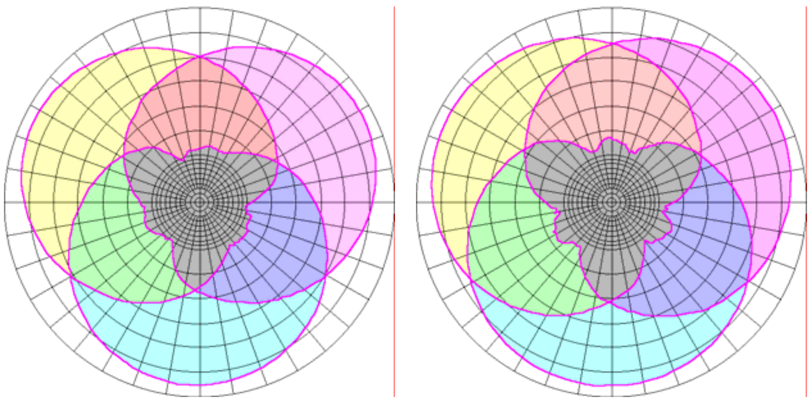
Lower Co-Channel Interference/Better Capacity & Quality

In a three sector site, traditional antennas produce a high degree of imperfect power control or sector overlap.

Imperfect sectorization presents opportunities for:

- **Increased softer hand-offs**
- **Interfering signals**
- **Dropped calls**
- **Reduced capacity**

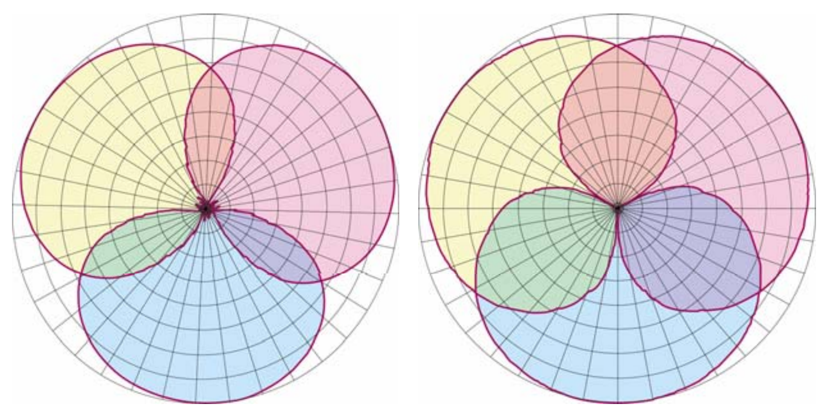
Traditional Flat Panels



Log Periodics (Example)

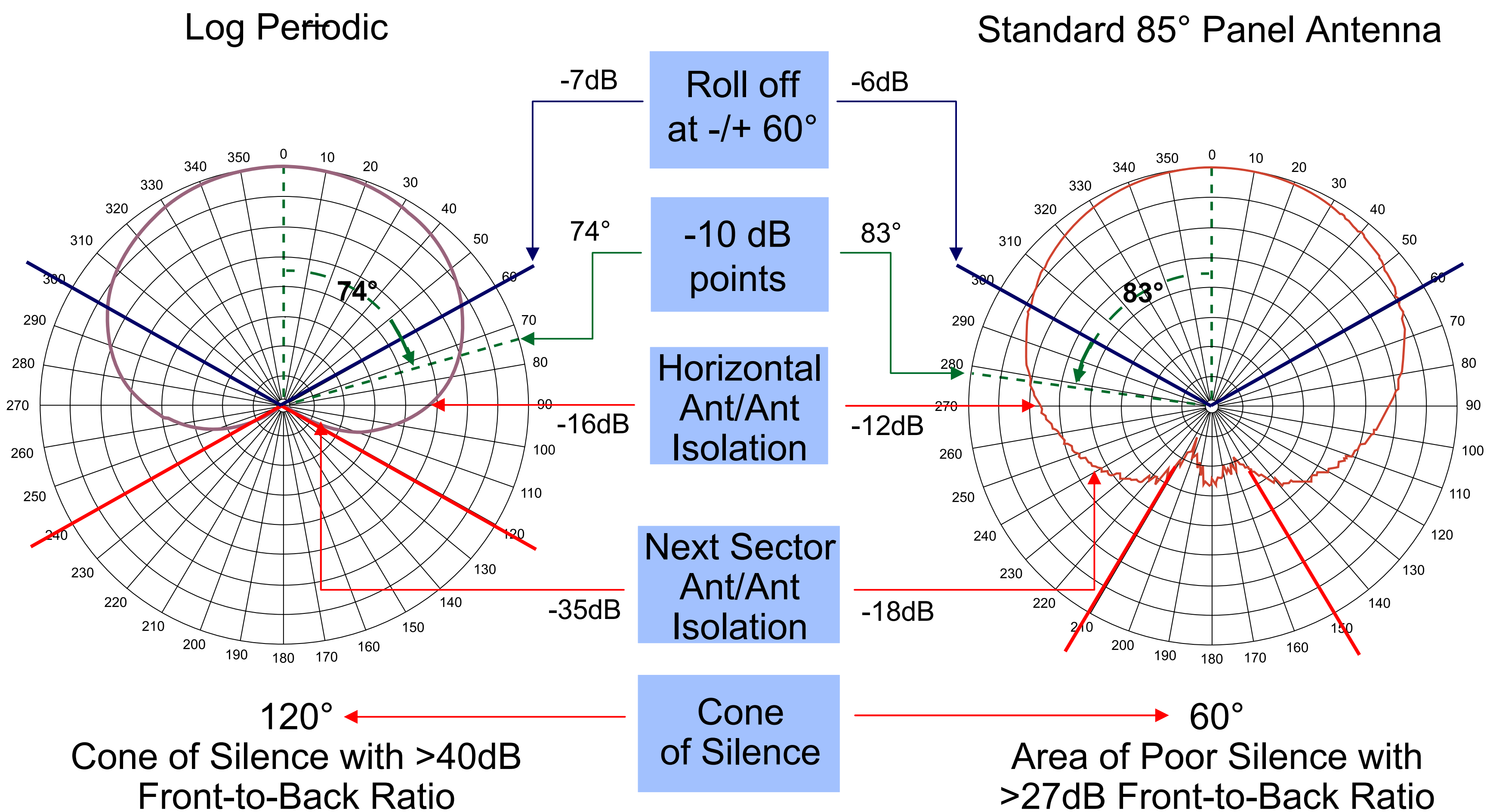
The rapid roll-off of the lower lobes of the log periodic antennas create larger, better defined "cones of silence" behind the array.

- **Much smaller softer hand-off area**
- **Dramatic call quality improvement**
- **5% - 10 % capacity enhancement**

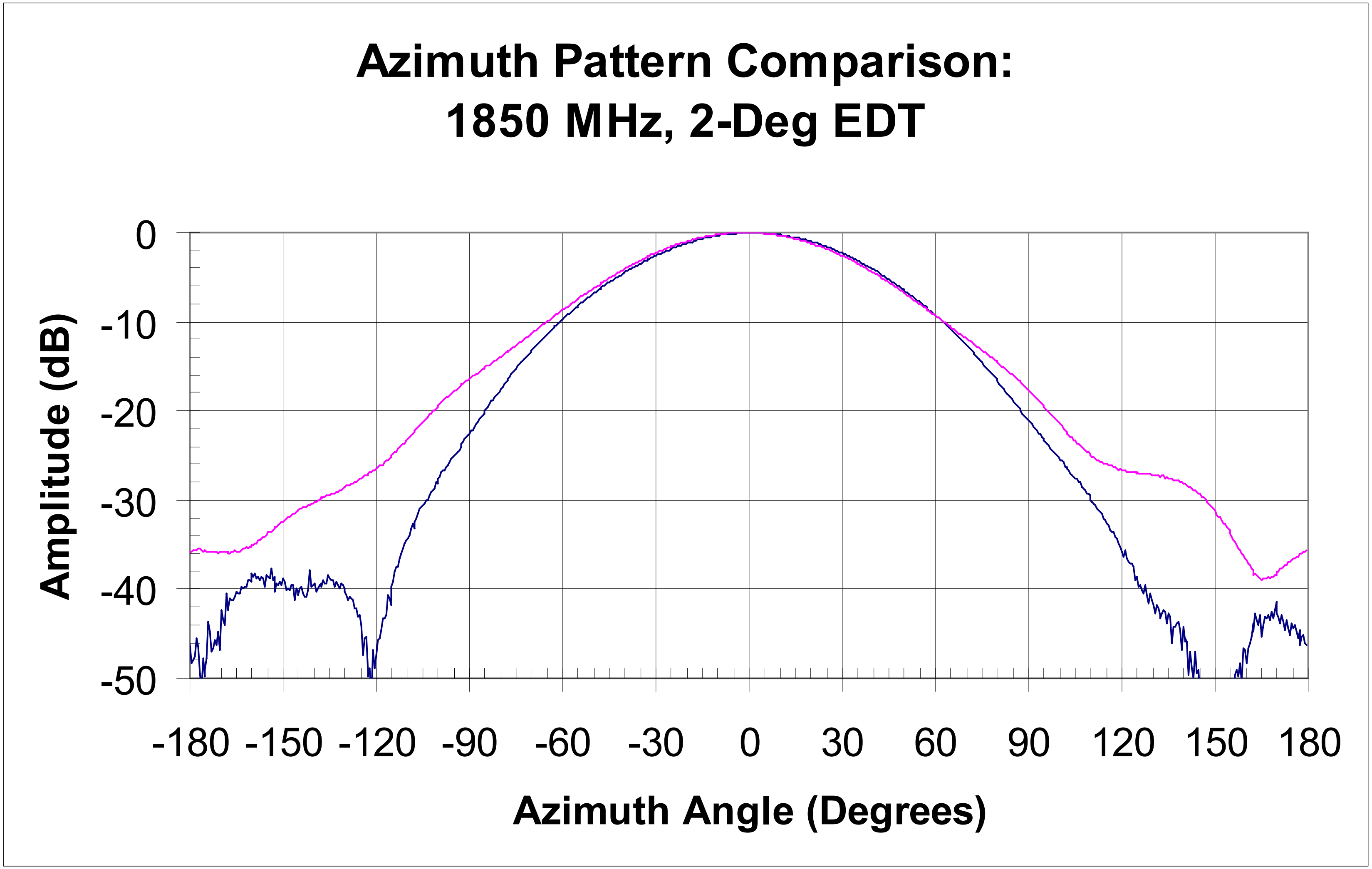


Antenna-Based System Improvements

Key antenna parameters to examine closely…



Dipole vs. LP Element



System Issues

- Choosing sector antennas
- Downtilt – electrical vs. mechanical
- RET optimization
- Passive intermodulation (PIM)
- Return loss through coax
- Pattern distortion, alignment, orientation
- Antenna isolation

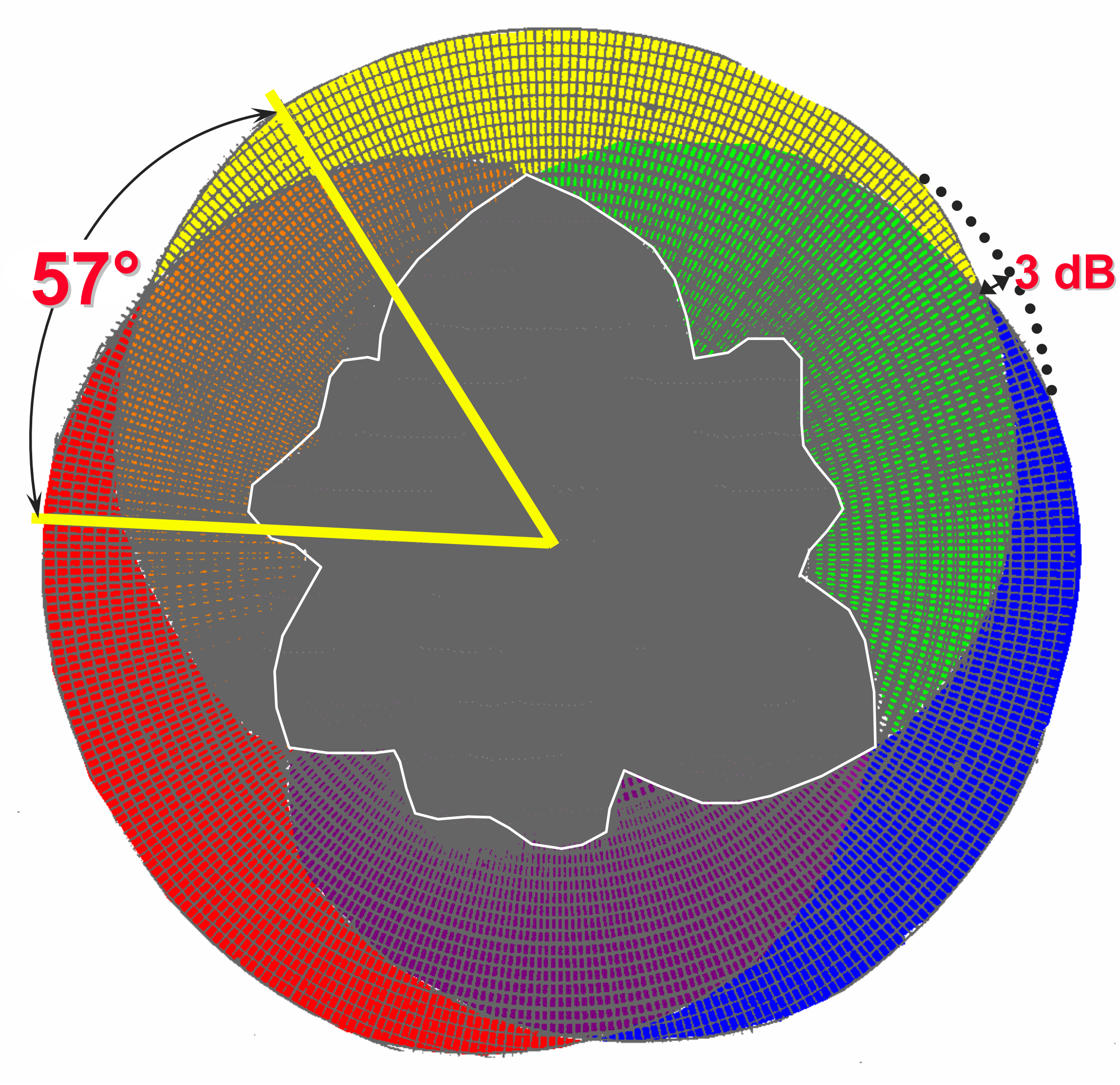
Choosing Sector Antennas

For 3 sector cell sites, what performance differences can be expected from the use of antennas with different horizontal apertures?

Criteria:

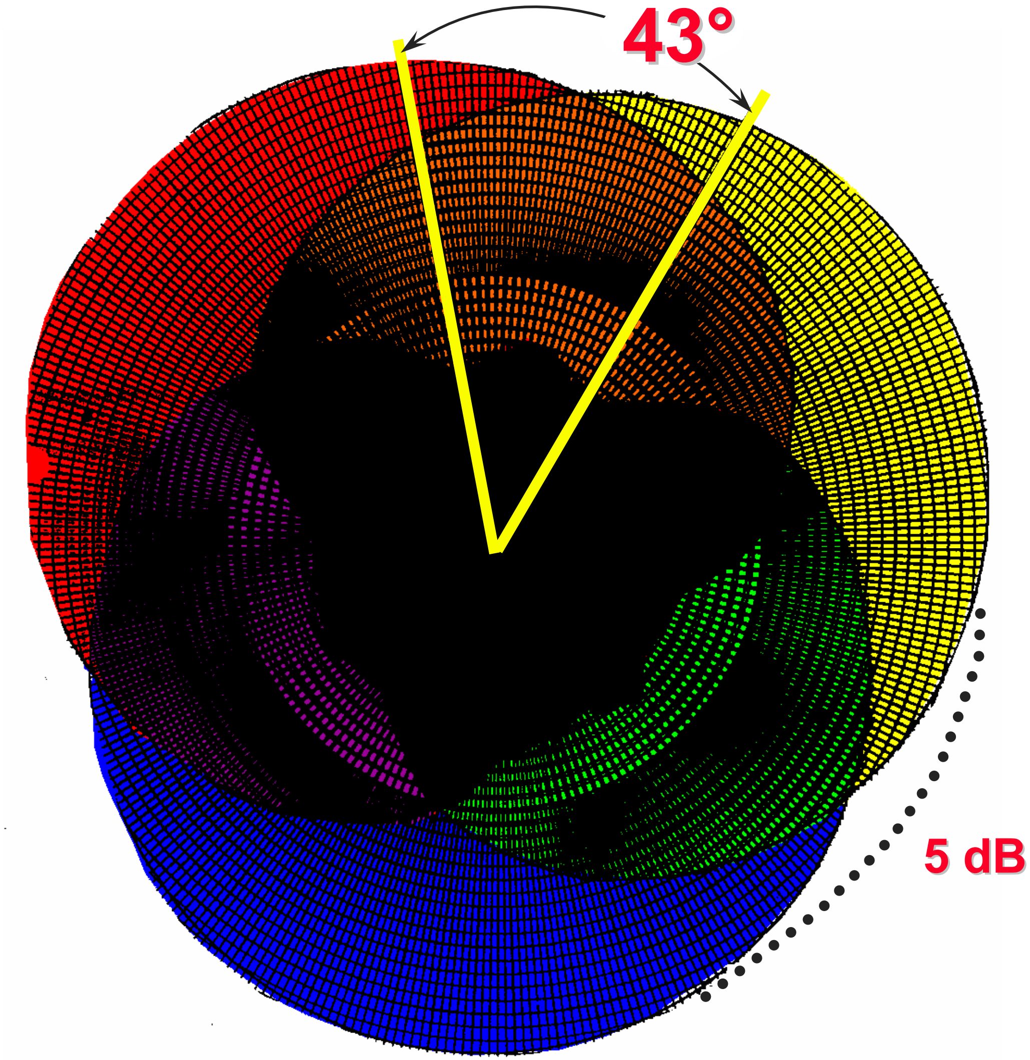
- Area of service indifference between adjacent sectors ("ping-pong" area).
- For comparison, use 6 dB differentials.
- Antenna gain and overall sector coverage.

3 x 120° Antennas



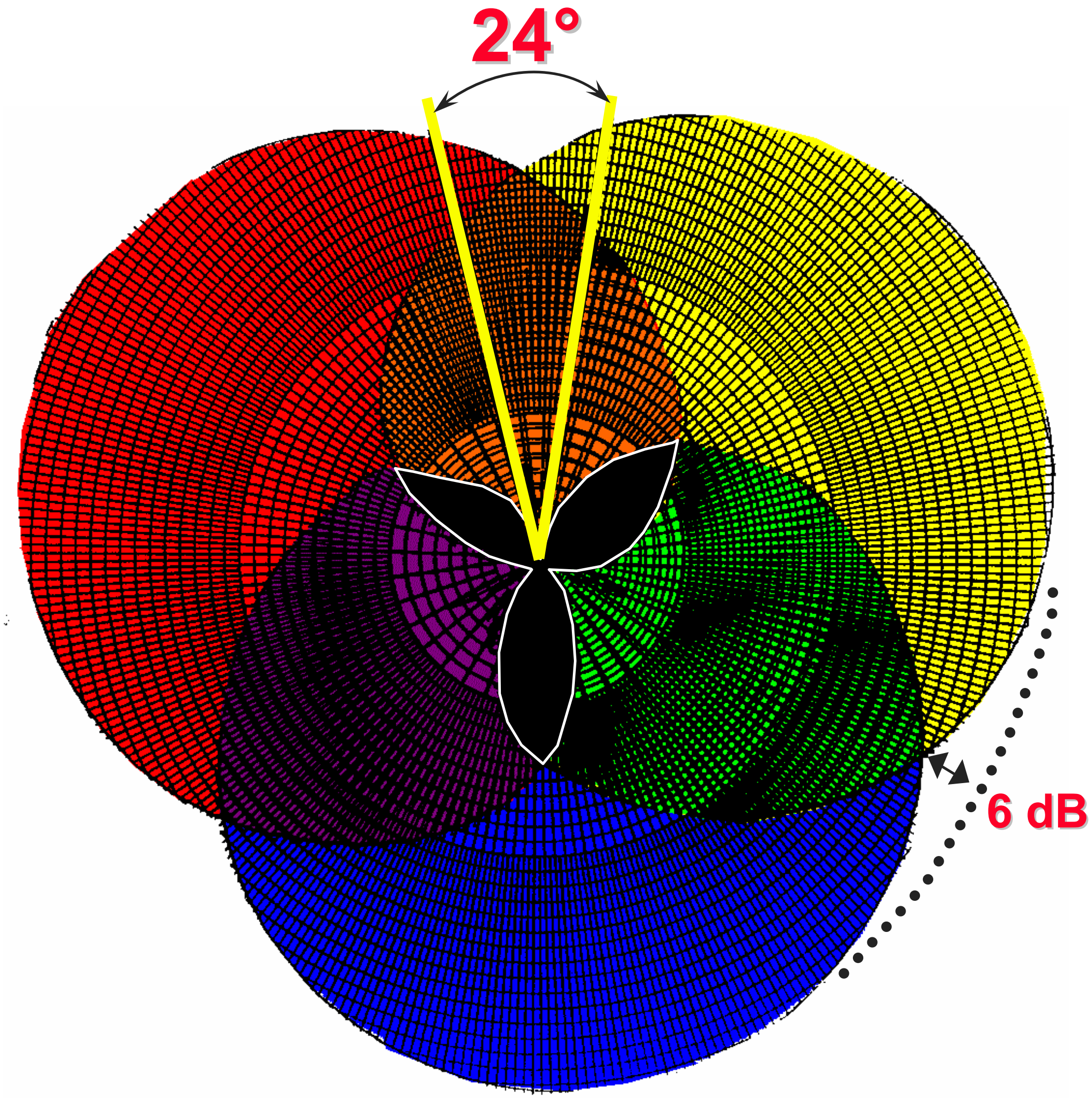
120°
Horizontal
Overlay
Pattern

3 x 90° Antennas



90° Horizontal Overlay Pattern

3 x 65° Antennas



65° Horizontal Overlay Pattern

Beam Downtilt

In urban areas, service and frequency utilization are frequently improved by directing maximum radiation power at an area below the horizon.

This Technique:

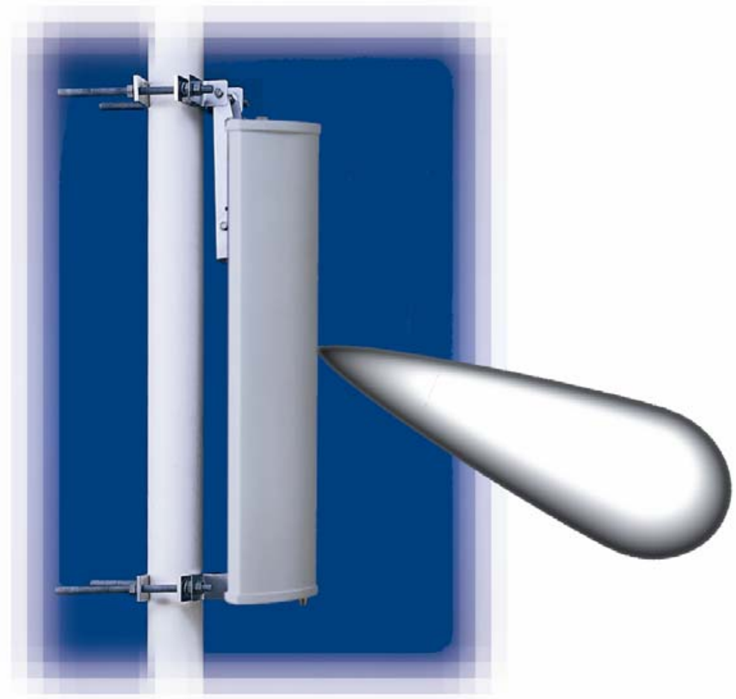
- Improves coverage of open areas close to the base station.
- Allows more effective penetration of nearby buildings, particular high-traffic lower levels and garages.
- Permits the use of adjacent frequencies in the same general region.

Electrical/Mechanical Downtilt

- Mechanical downtilt lowers main beam, raises back lobe.
- Electrical downtilt lowers main beam and lowers back lobe.
- A combination of equal electrical and mechanical downtilts lowers main beam and brings back lobe onto the horizon!

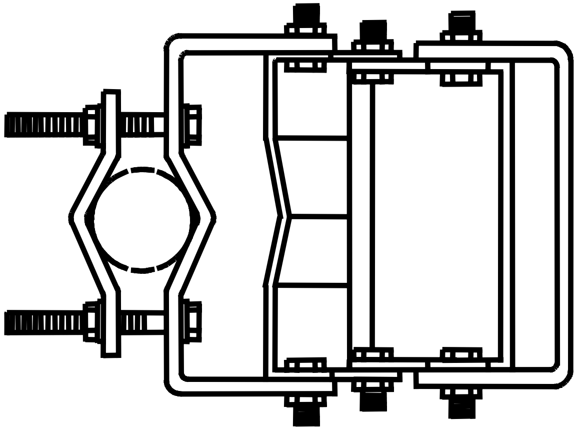
Electrical/Mechanical Downtilt

Mechanical

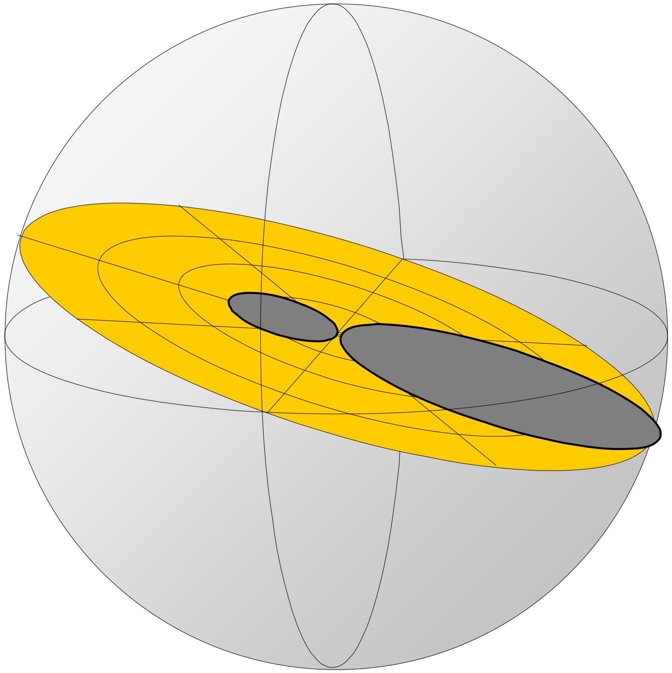


Electrical

Mechanical Downtilt Mounting Kit



Mechanical Downtilt

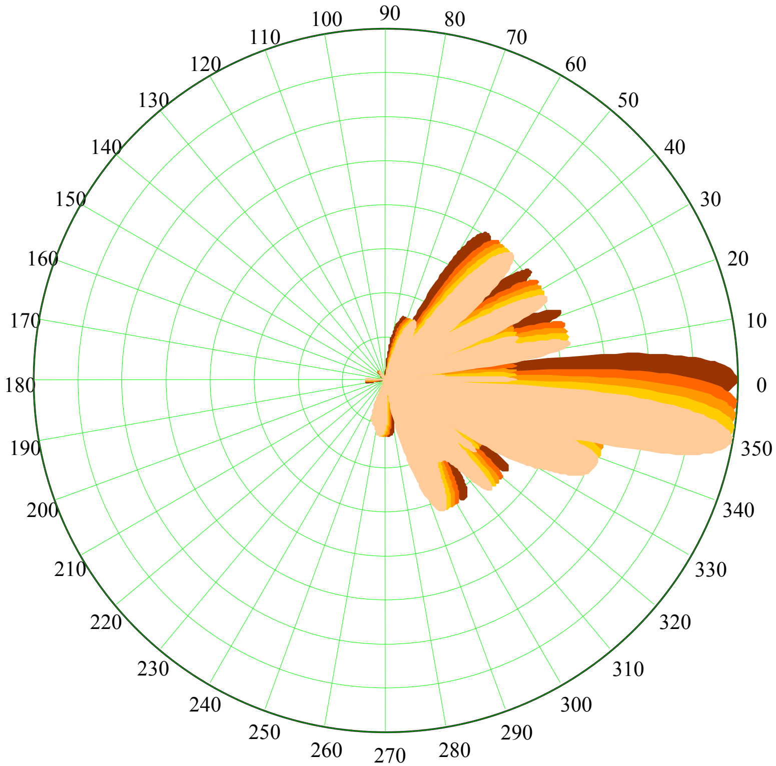


Mechanical Tilt Causes:

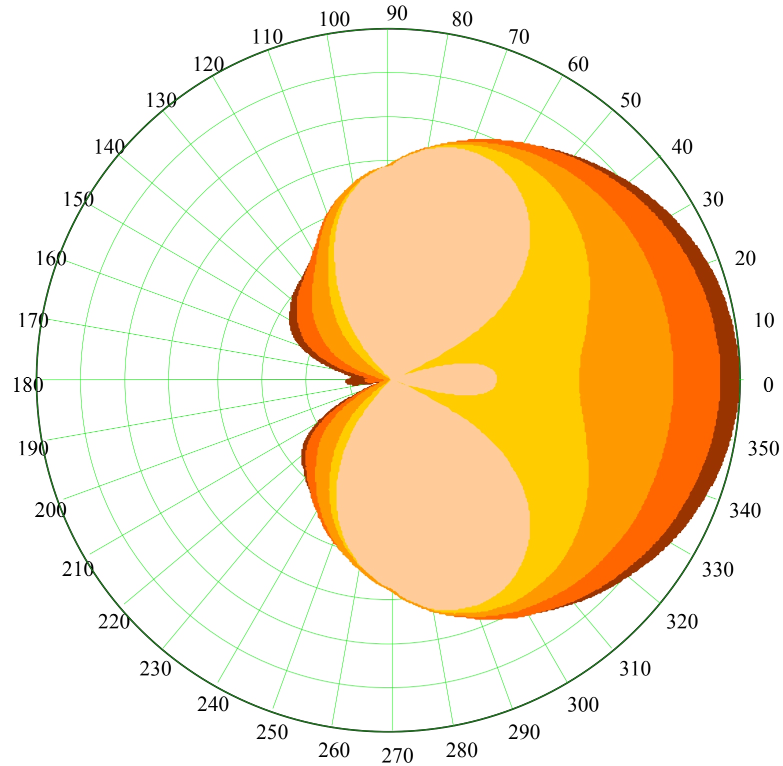
- Beam Peak to Tilt Below Horizon
- Back Lobe to Tilt Above Horizon
- At ± 90° No Tilt

Pattern Analogy: Rotating a Disk

Mechanical Downtilt Coverage



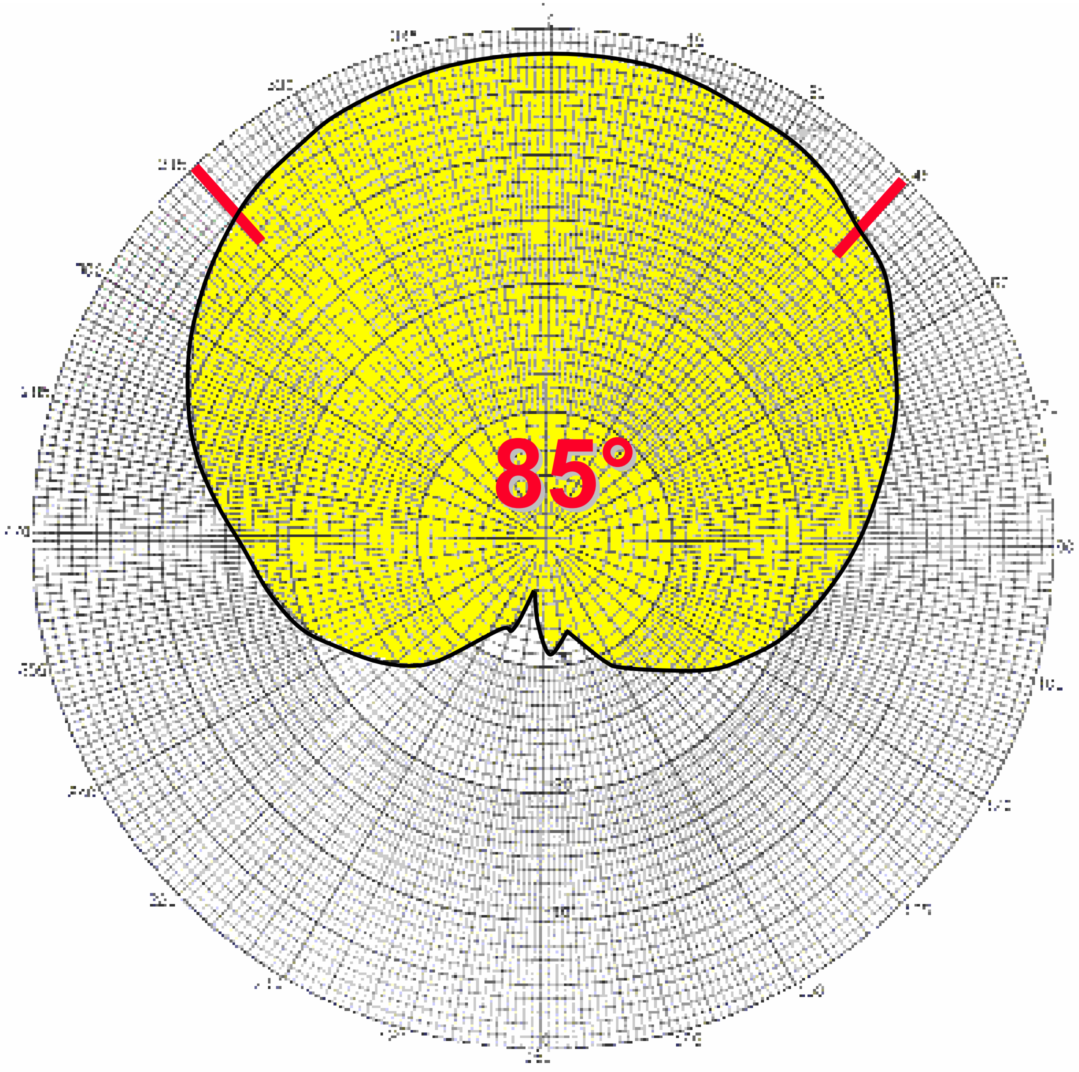
Elevation Pattern



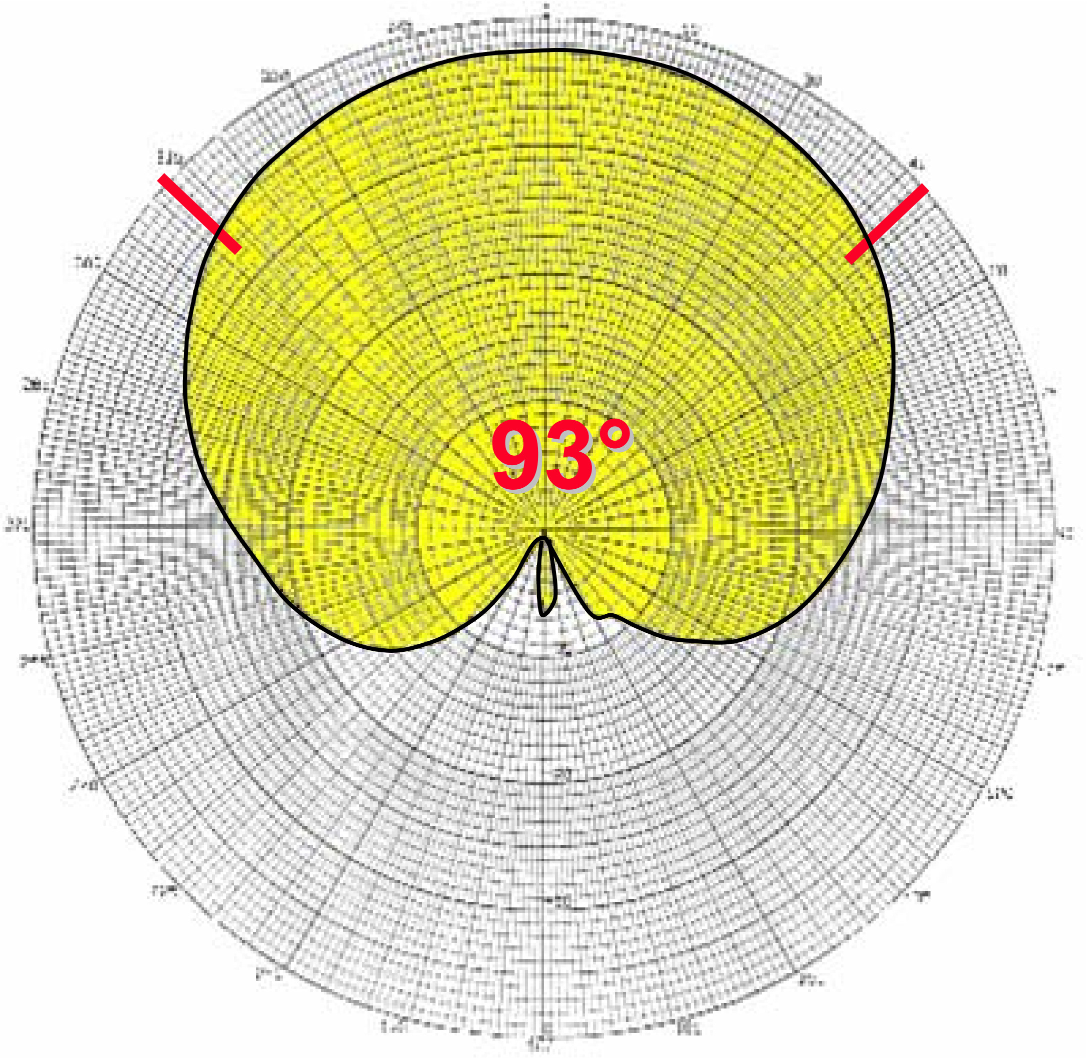
Azimuth Pattern

Mechanical Tilt	0°	4°	6°	8°	10°

Sample Antenna
0° Mechanical Downtilt

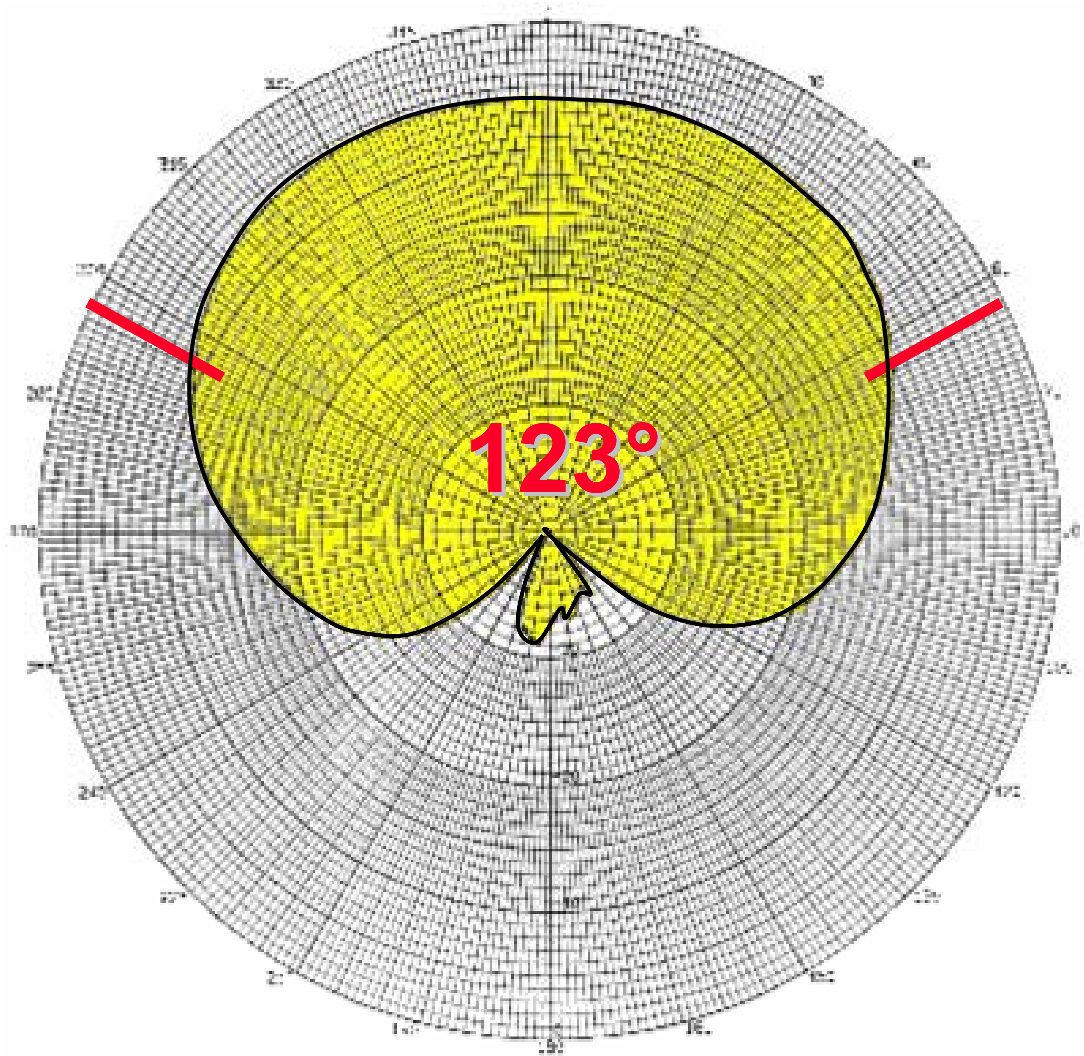


Sample Antenna
7° Mechanical Downtilt

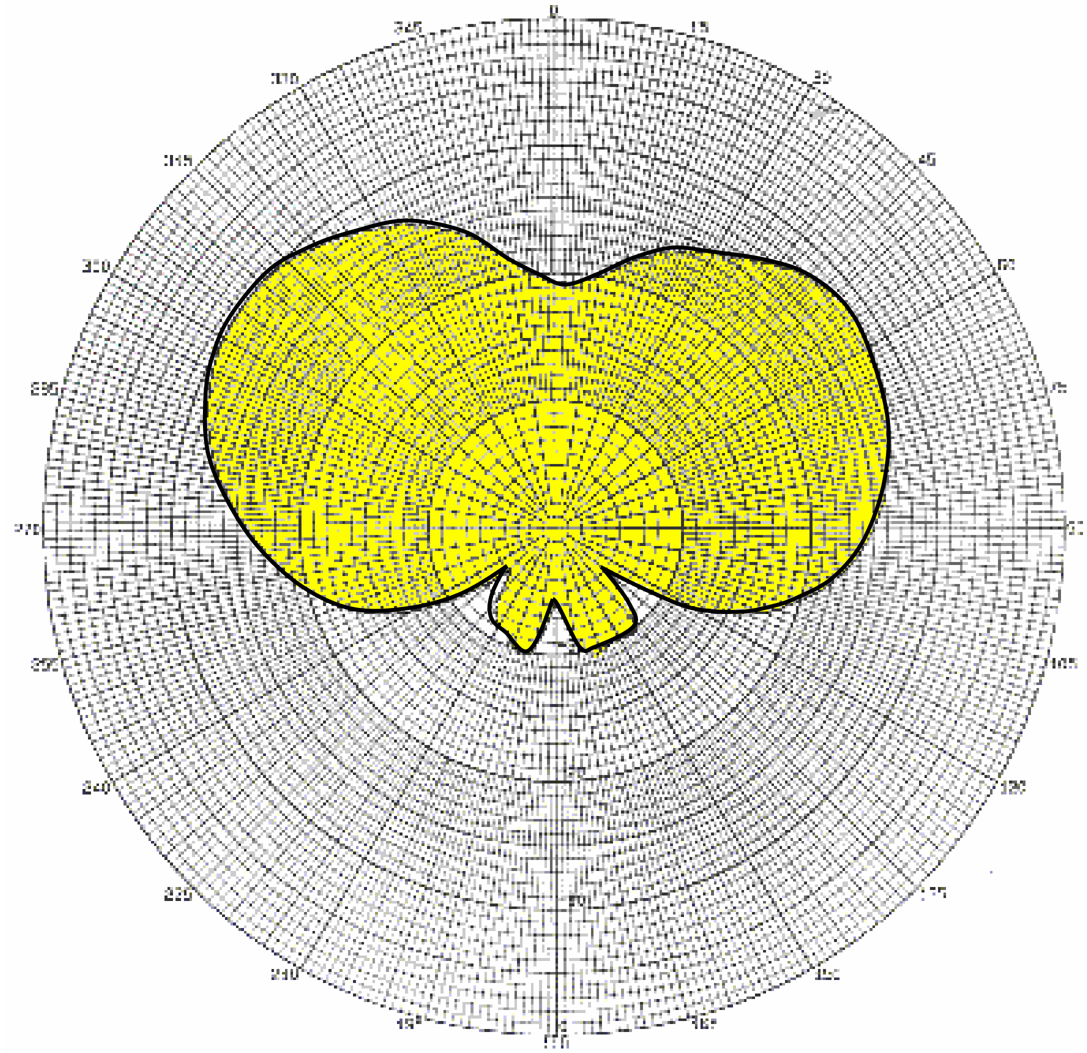


Sample Antenna

15° Mechanical Downtilt



Sample Antenna
20° Mechanical Downtilt



Horizontal
3 dB Bandwidth
Undefined

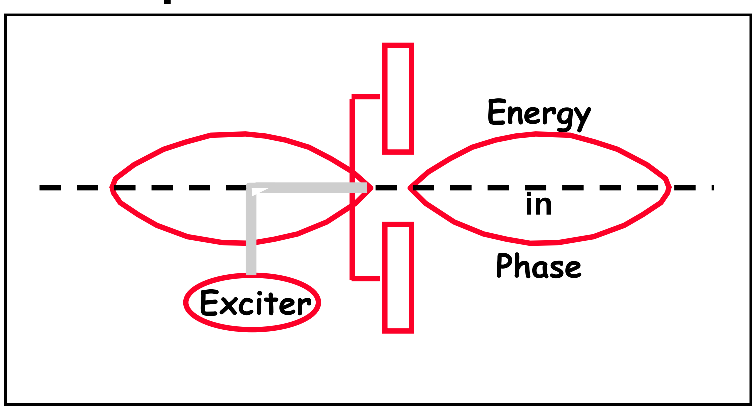
Managing Beam Tilt

For the radiation pattern to show maximum gain in the direction of the horizon, each stacked dipole must be fed from the signal source “in phase”. Feeding vertically arranged dipoles “out of phase” will generate patterns that “look up” or “look down”.

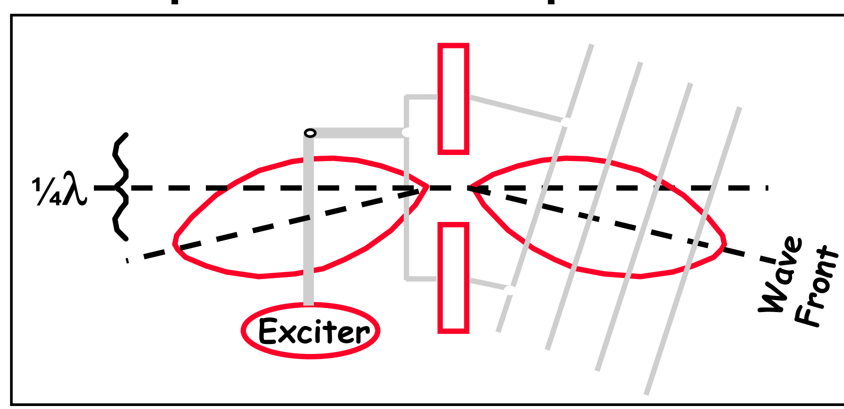
The degree of beam tilt is a function of the phase shift of one dipole relative to the adjacent dipole and their physical spacing.

Generating Electrical Beam Tilt

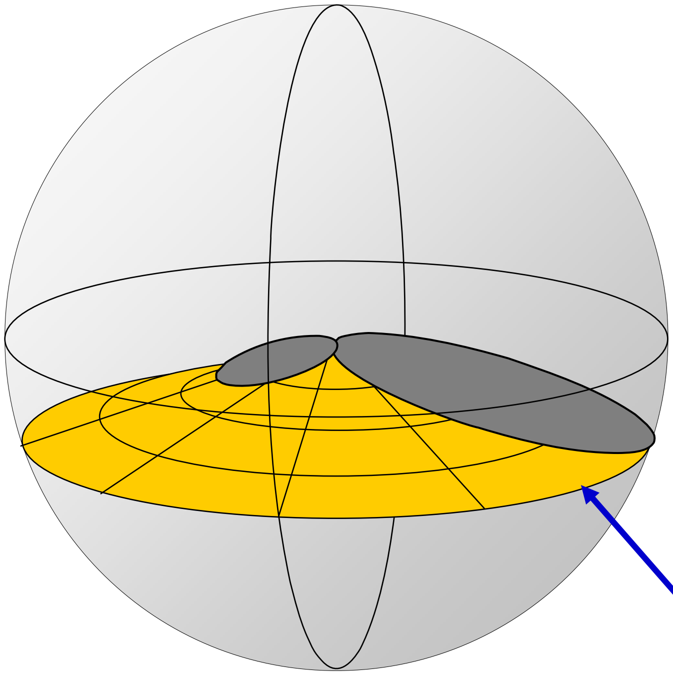
Dipoles Fed w/ Uniform Phase



Dipoles Fed w/ Sequential Phase



Electrical Downtilt



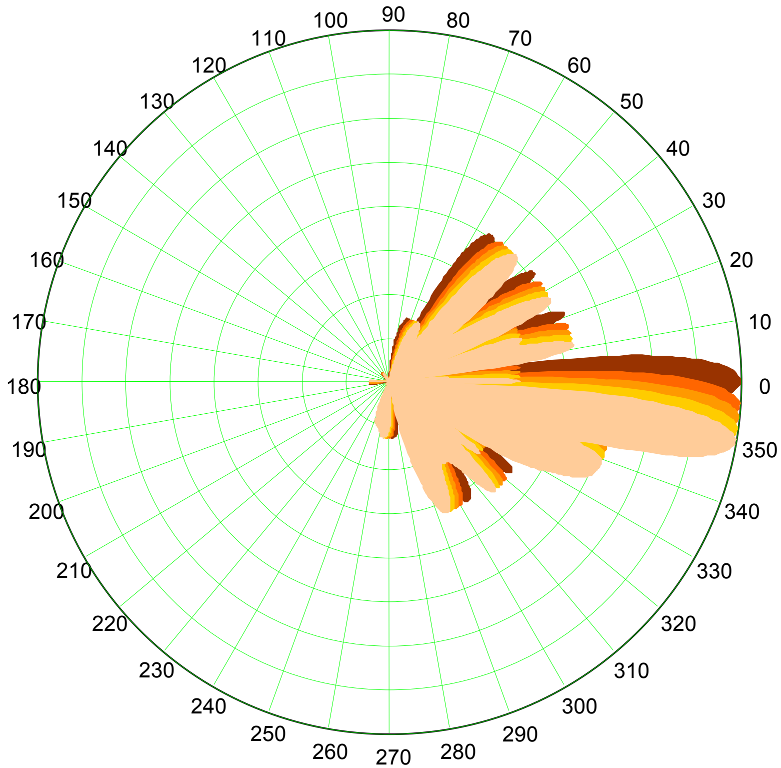
Electrical Tilt Causes:

- Beam Peak to Tilt Below Horizon
- Back Lobe to Tilt Below Horizon
- All portions of the Pattern Tilts

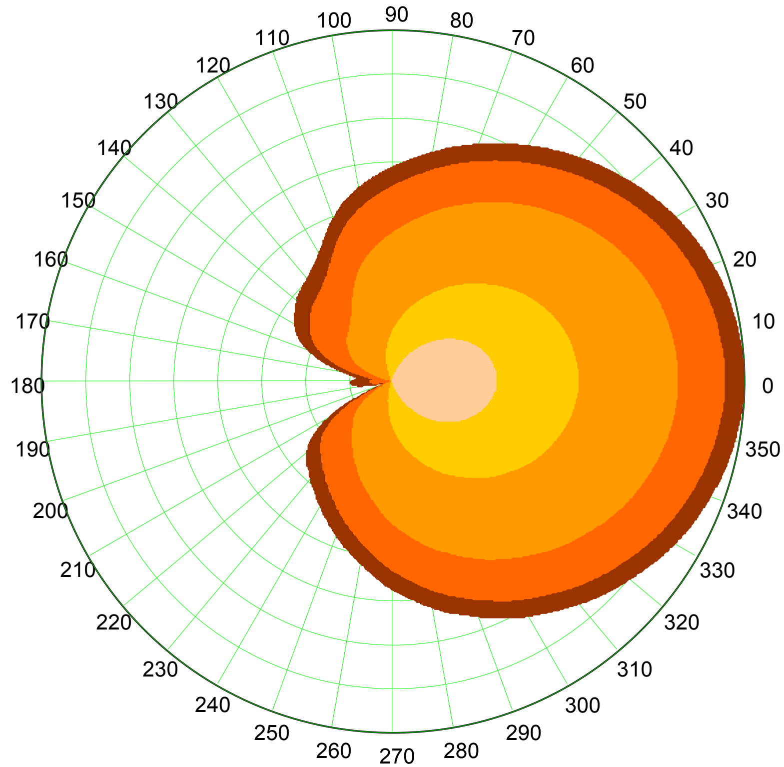
“Cone” of the Beam Peak Pattern

Pattern Analogy: Forming a Cone Out of a Disk

Electrical Downtilt Coverage



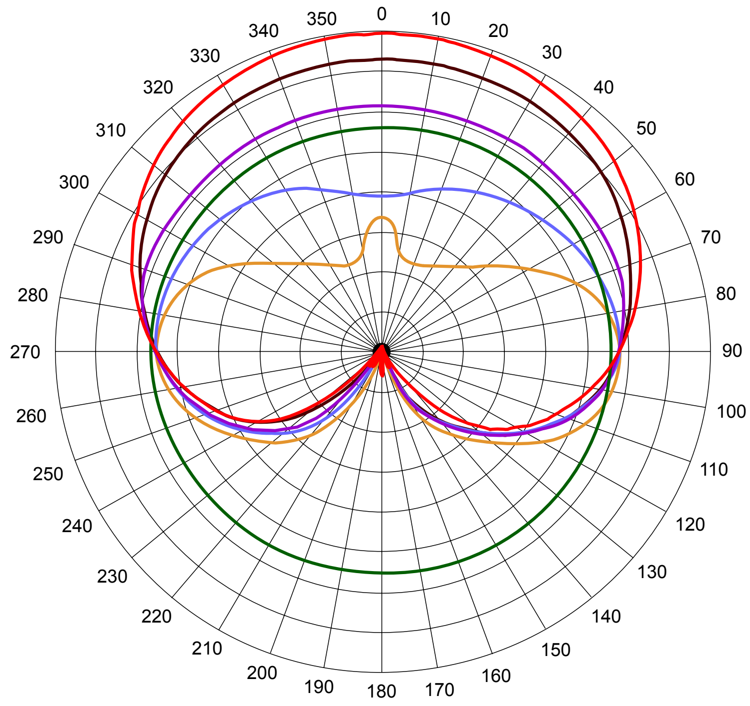
Elevation Pattern

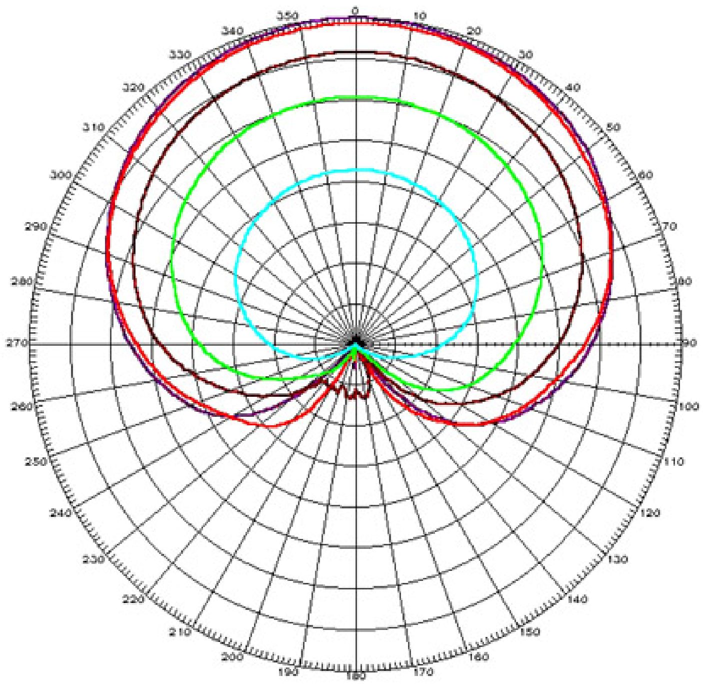


Azimuth Pattern

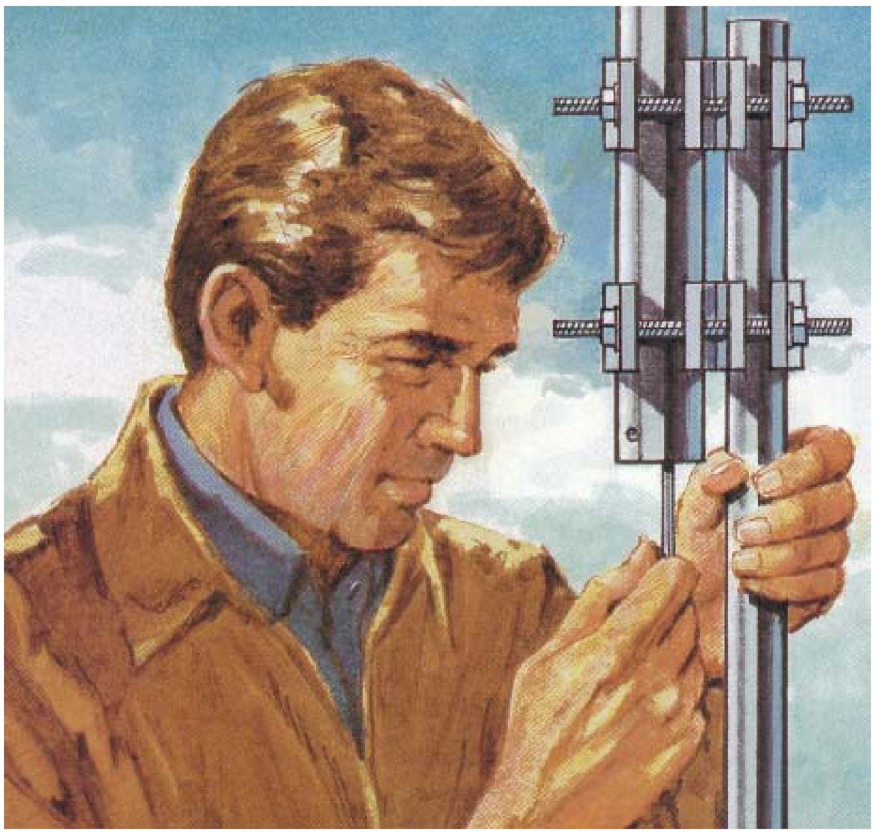
Electrical Tilt	0°	4°	6°	8°	10°

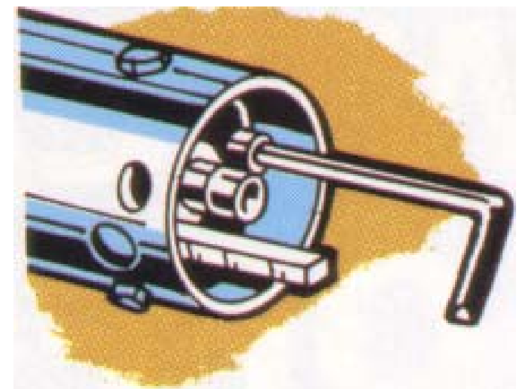
Mechanical vs. Electrical Downtilt



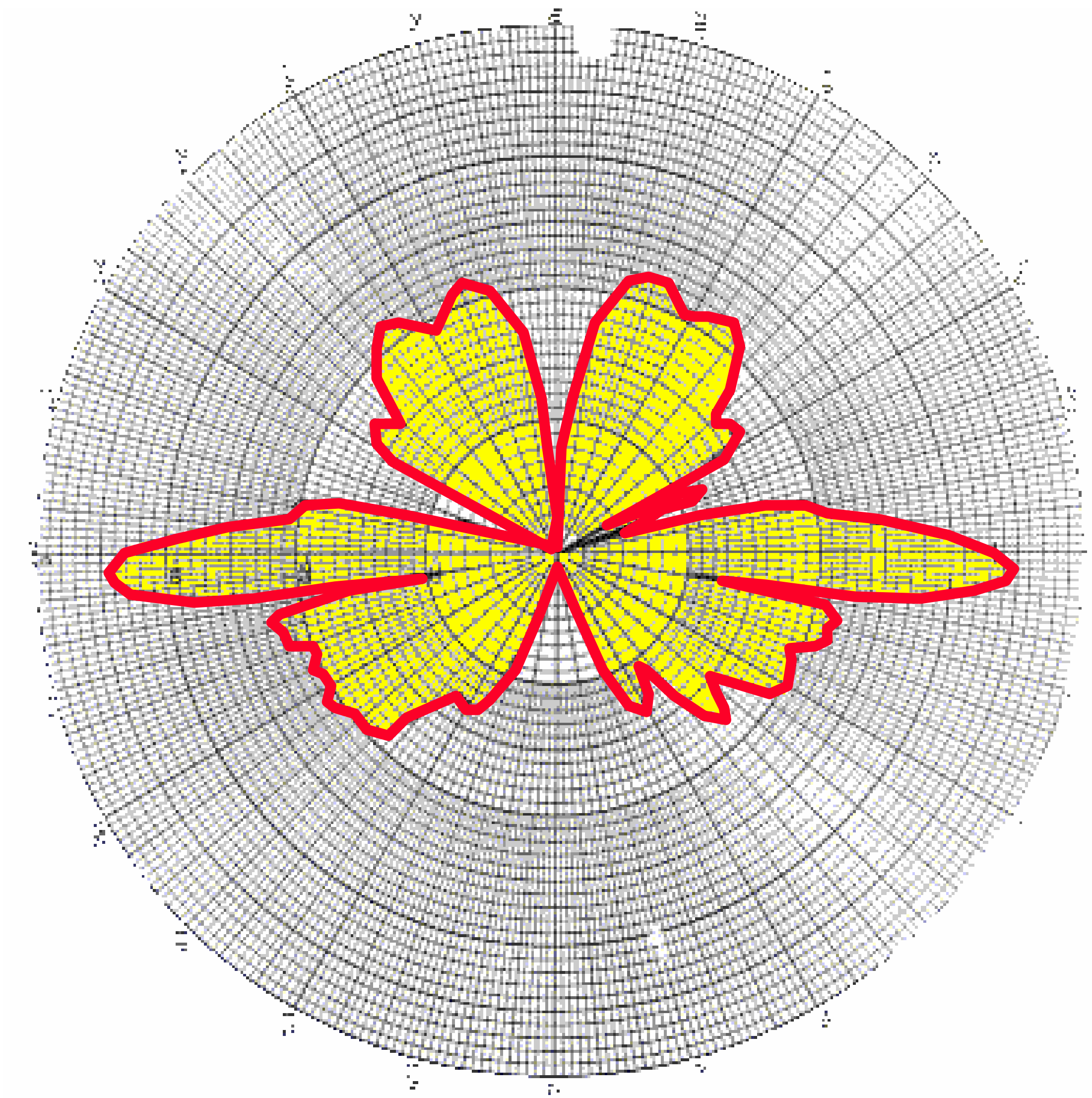


With Variable Electrical Downtilt (VED), you can adjust anywhere in seconds.

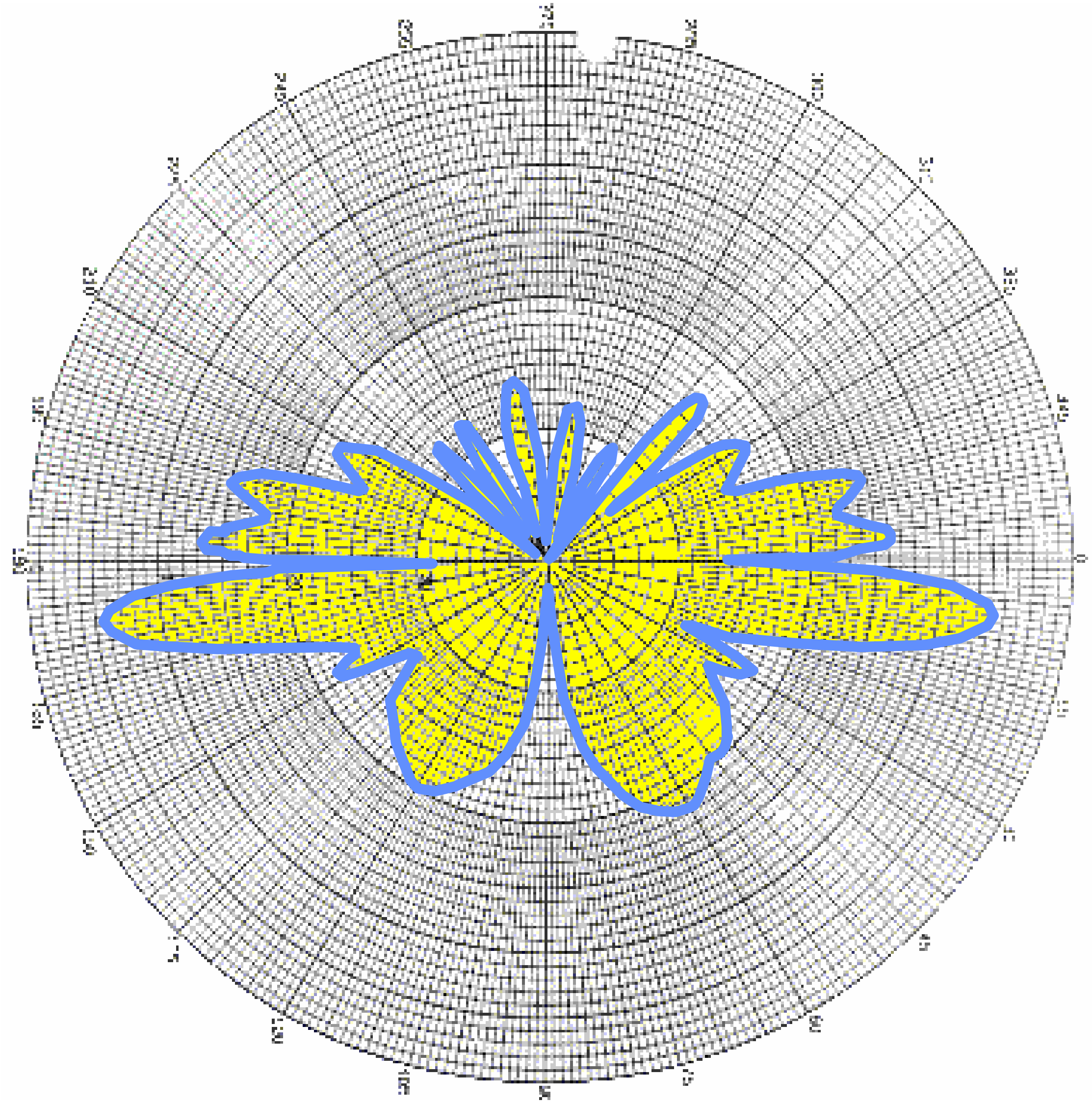




Sample Antenna
3° Electrical Downtilt

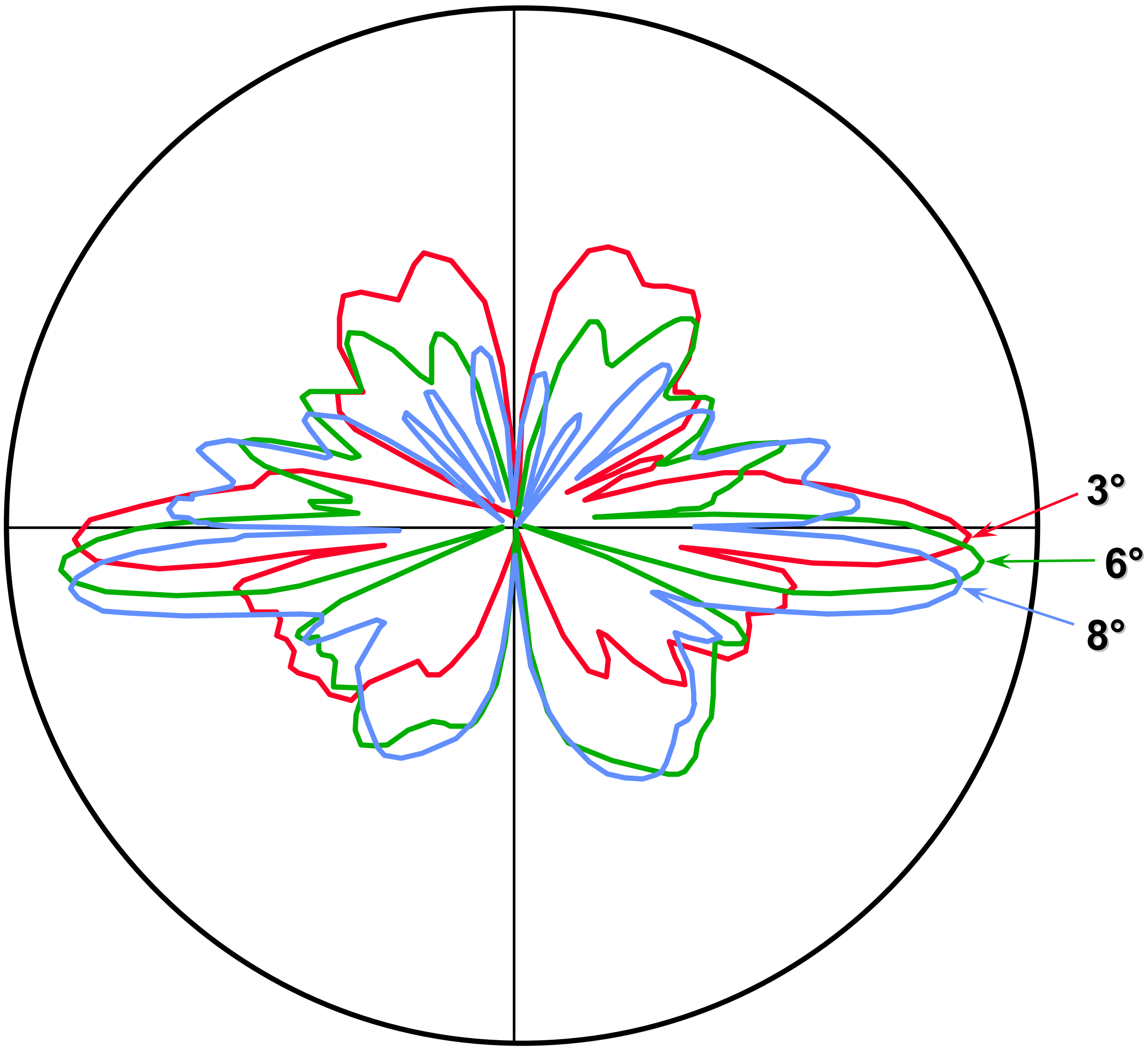


Sample Antenna
8° Electrical Downtilt

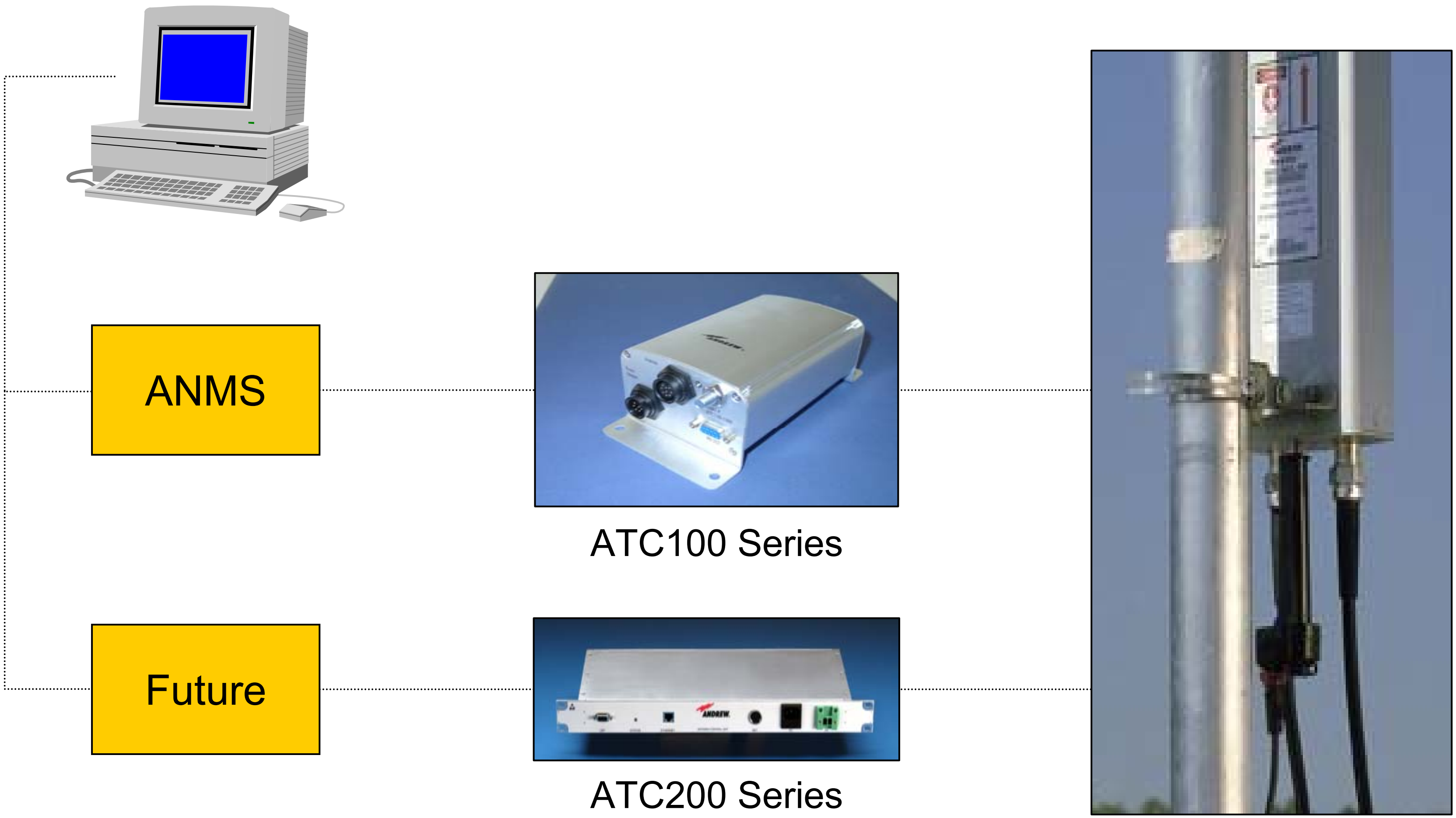


Sample Antenna

Overlay Electrical Downtilt



Remote Electrical Downtilt (RET)
Optimization

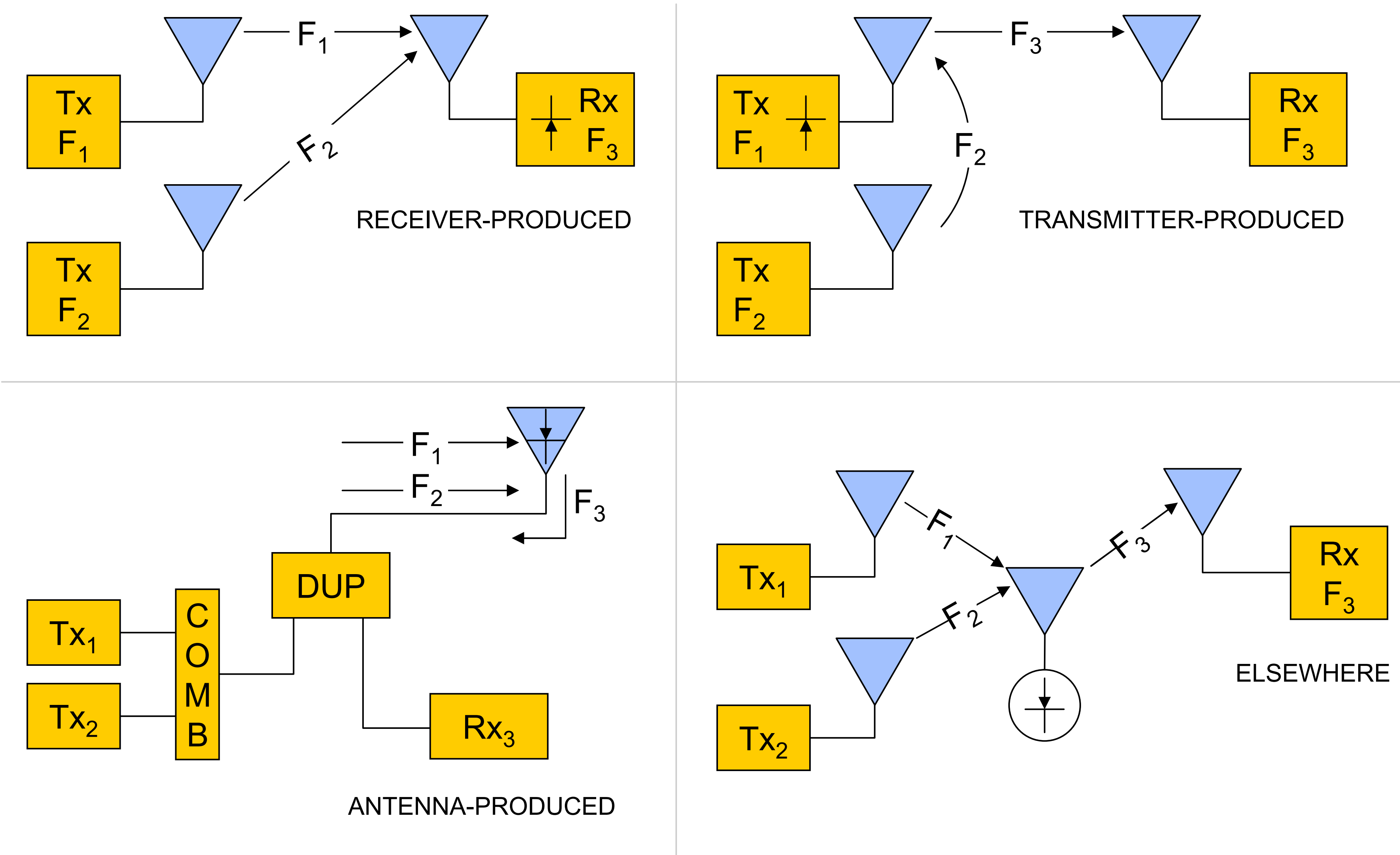


BREAK

Causes of Inter-Modulation Distortion

- Ferromagnetic materials in the current path:
  - Steel
  - Nickel Plating or Underplating
- Current Disruption:
  - Loosely Contacting Surfaces
  - Non-Conductive Oxide Layers Between Contact Surfaces

"Intermod" Interference
Where?



Remember dBc?

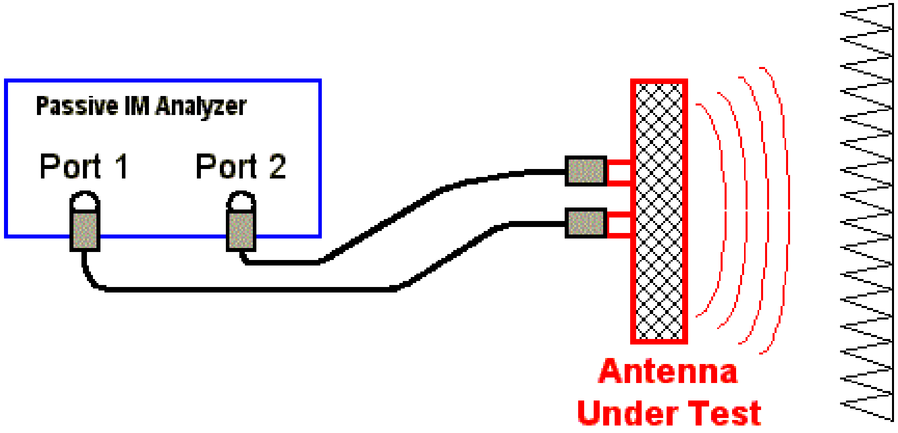
"dBc" with antennas work like this

- 2 tones @ 20Watts = 43dBm
- Scan for 3rd order of those 2 carriers
- If 3rd order = -110dBm then that = -153dBc

  110dBm + 43dBm = 153dBc

IMD – Inter-Modulation Distortion

PIM – Passive Inter-Modulation



PCS A-Band
Product Frequencies, Two-Signal IM

$F_{IM} = nF_1 \pm mF_2$

Example: F_1 = 1945 MHz; F_2 = 1930 MHz

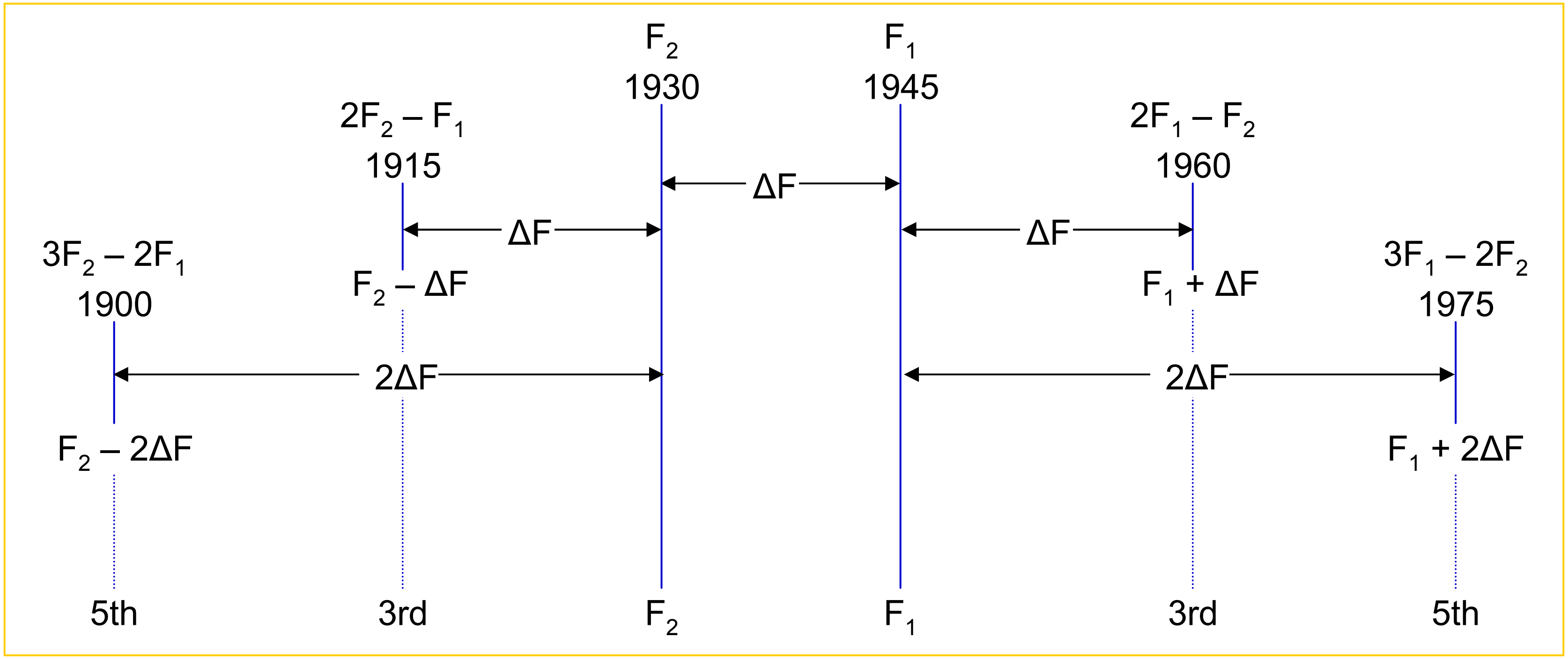
n	m	Product Order	Product Formulae	Product Frequencies (MHz)
1	1	Second	$1F_1 + 1F_2$ $1F_1 - 1F_2$	3875 15
2	1	Third	$2F_1 + 1F_2$ $*2F_1 - 1F_2$	5820 1960
1	2	Third	$2F_2 + 1F_1$ $*2F_2 - 1F_1$	5805 1915
2	2	Fourth	$2F_1 + 2F_2$ $2F_1 - 2F_2$	7750 30
3	2	Fifth	$3F_1 + 2F_2$ $*3F_1 - 2F_2$	9695 1975
2	3	Fifth	$3F_2 + 2F_1$ $*3F_2 - 2F_1$	9680 1900

*Odd-order difference products fall in-band.

Two-Signal IM
Odd-Order Difference Products

Example: F_1 = 1945 MHz; F_2 = 1930 MHz

$\Delta F = F_1 - F_2 = 15$



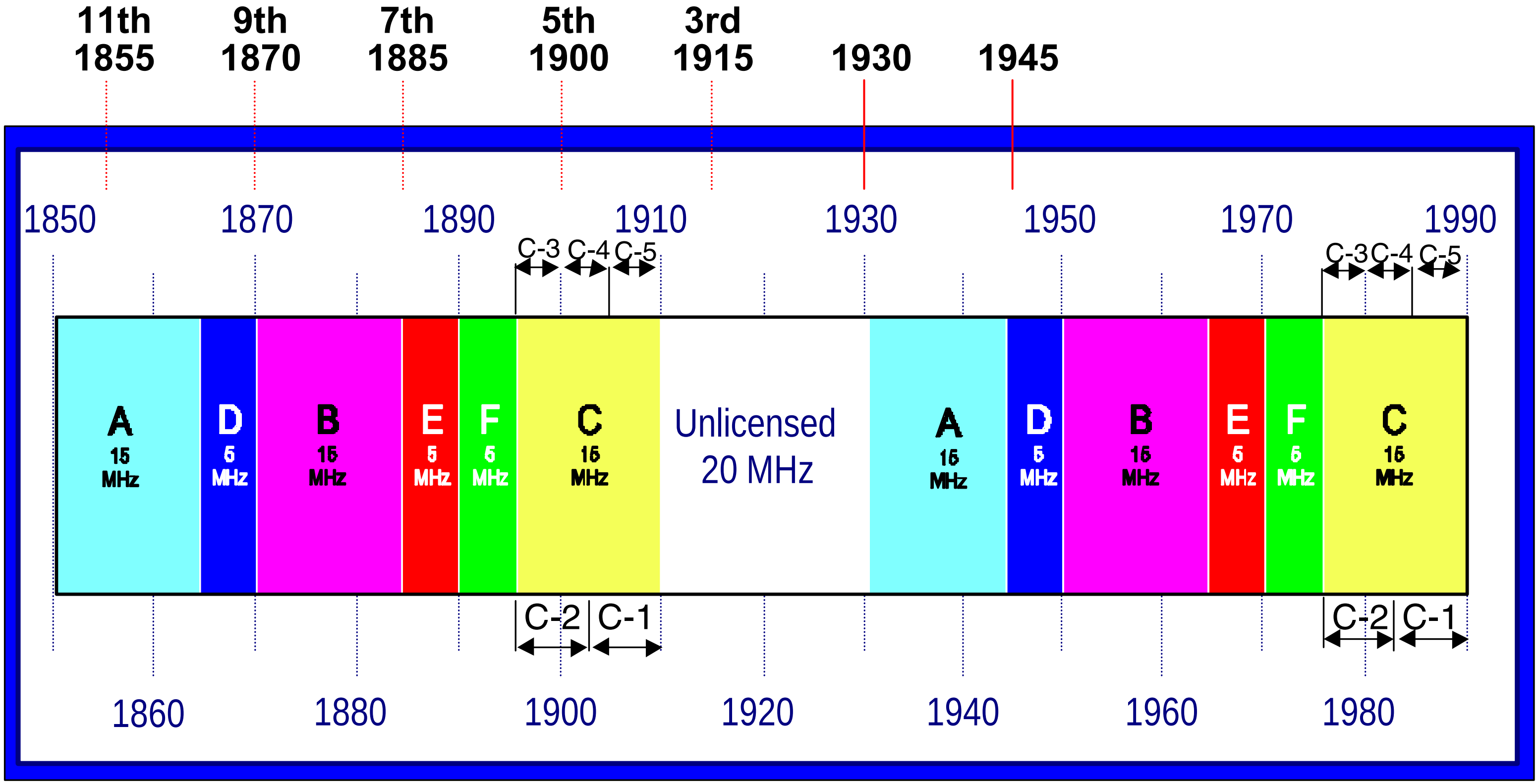
Third Order:	$F_1 + \Delta F$; $F_2 - \Delta F$
Fifth Order:	$F_1 + 2\Delta F$; $F_2 - 2\Delta F$
Seventh Order::	$F_1 + 3\Delta F$; $F_2 - 3\Delta F$

“Higher than the highest – lower than the lowest – none in-between”

PCS Duplexed IM

Band	Tx Frequency	Rx Frequency	Own Rx Band IM Order	Any Rx Band IM Order	IM Equations Own Rx Band	Any Rx Band
A	1930-1945	1850-1865	11th	5th	=6*Tx(low)-5*Tx(high)=1855	=3*Tx(low)-2*Tx(high)=1900
B	1950-1965	1870-1885	11th	7th	=6*Tx(low)-5*Tx(high)=1875	=4*Tx(low)-3*Tx(high)=1905
C	1975-1990	1895-1910	11th	11th	=6*Tx(low)-5*Tx(high)=1900	=6*Tx(low)-5*Tx(high)=1900

A Band IM

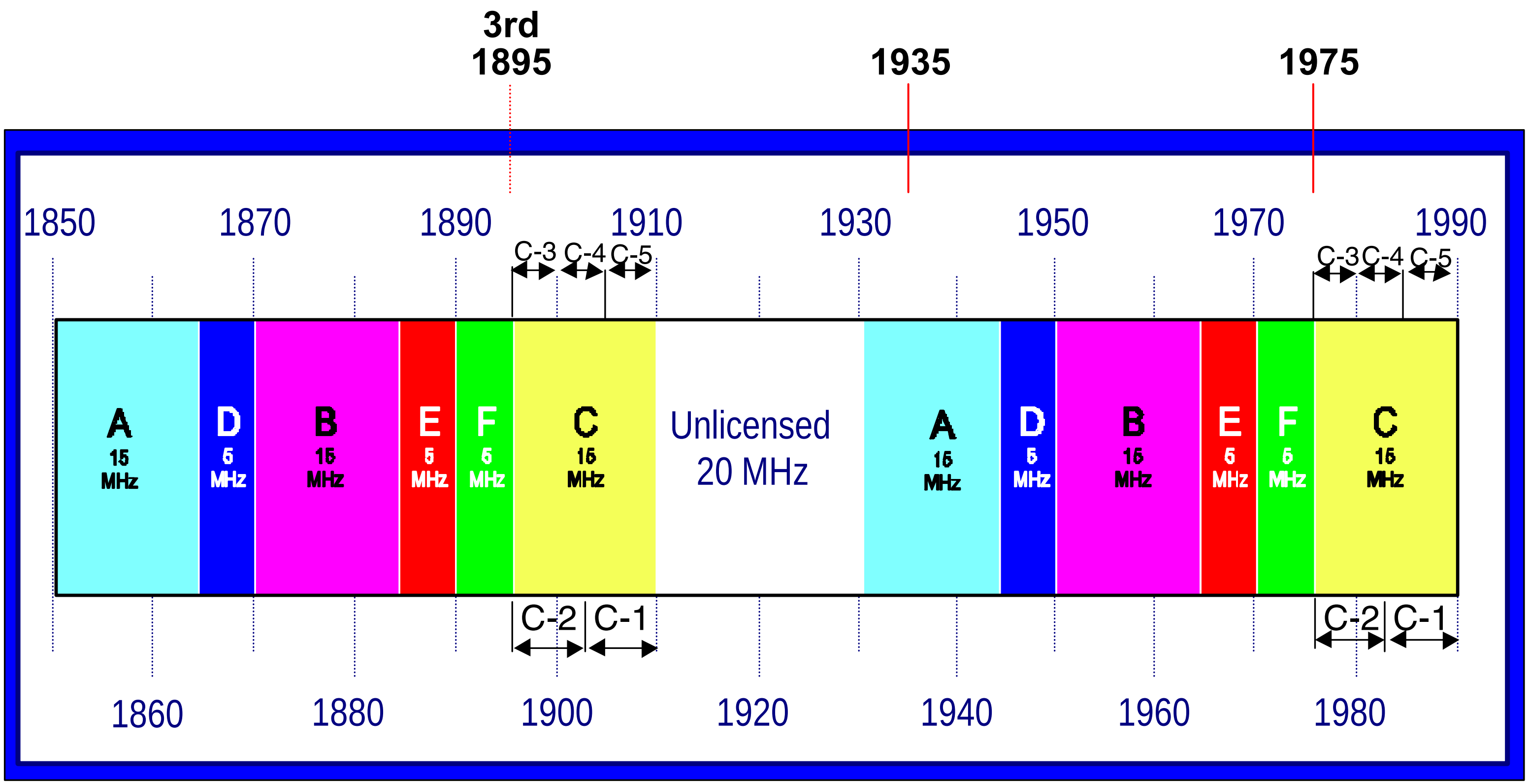


FCC Broadband PCS Band Plan

Channel Block	Bandwidth (MHz)	Frequencies
C	30	1895-1910, 1975-1990
C1	15	1902.5-1910, 1982.5-1990
C2	15	1895-1902-5, 1975-1982.5
C3	10	1895-1900, 1975-1980
C4	10	1900-1905, 1980-1985
C5	10	1905-1910, 1985-1990

Note: Some of the original C Block licenses (Originally 30 MHz each) were split into multiplelicenses (C-1 and C-2: 15 MHz; C-3, C-4, and C-5: 10MHz).

A and F Band IM



Channel Block	Bandwidth (MHz)	Frequencies
C	30	1895-1910, 1975-1990
C1	15	1902.5-1910, 1982.5-1990
C2	15	1895-1902-5, 1975-1982.5
C3	10	1895-1900, 1975-1980
C4	10	1900-1905, 1980-1985
C5	10	1905-1910, 1985-1990

FCC Broadband PCS Band Plan

Note: Some of the original C Block licenses (Originally 30 MHz each) were split into multiplelicenses (C-1 and C-2: 15 MHz; C-3, C-4, and C-5: 10MHz).

System VSWR Calculator

Frequency (MHz):	895.00

System Component	Max. VSWR	Return Loss (dB)	Cable Type	Cable Length (m)	Cable Length (ft)	Insertion Loss (dB)	Reflections at input
Antenna	1.33	16.98					0.0983
Top Jumper	1.07	29.42	LDF4-50A	1.22	4.00	0.08	0.0239
Main Feed Line	1.11	25.66	LDF5-50A	30.48	100.00	1.18	0.0484
Surge Suppressor	1.07	29.42				0.20	0.0329
Bottom Jumper	1.07	29.42	LDF4-50A	1.83	6.00	0.13	0.0338
						1.59	

Jumper Cable Types:
FSJ4-50B
LDF4-50A

Estimated System Reflection:	0.1216
Estimated System VSWR:	**1.28**
Estimated System Return Loss (dB):	**18.3**

Main Feedline Cable Types:
LDF5-50A
LDF6-50
LDF7-50A
VXL5-50
VXL6-50
VXL7-50

Maximum System Reflection:	0.2372
Maximum System VSWR:	**1.62**
Maximum System Return Loss (dB):	**12.5**

Total Insertion Loss (dB):	**1.59**

Return Loss to VSWR converter

Return Loss (dB)	VSWR
28.00	1.0829

Feet to meters converter

feet	meters
4.00	1.22

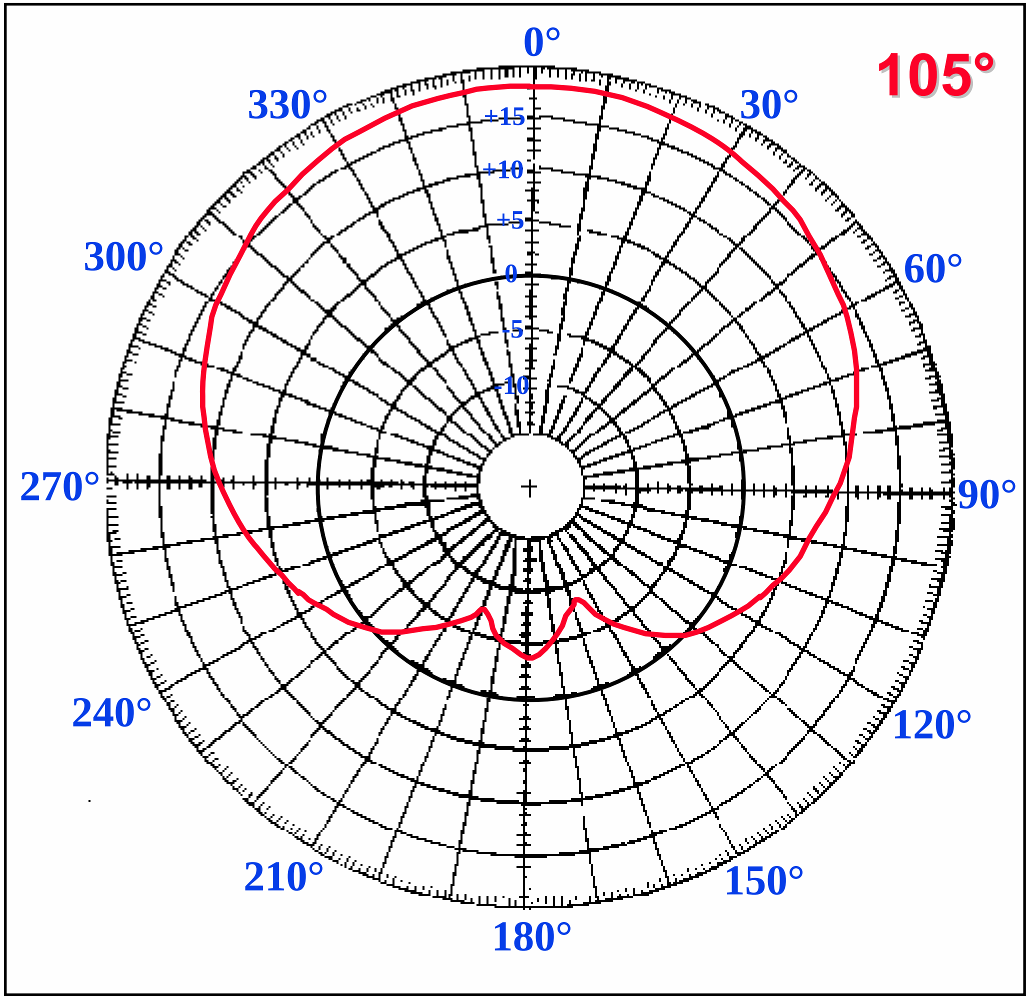
Antenna Pattern Distortions

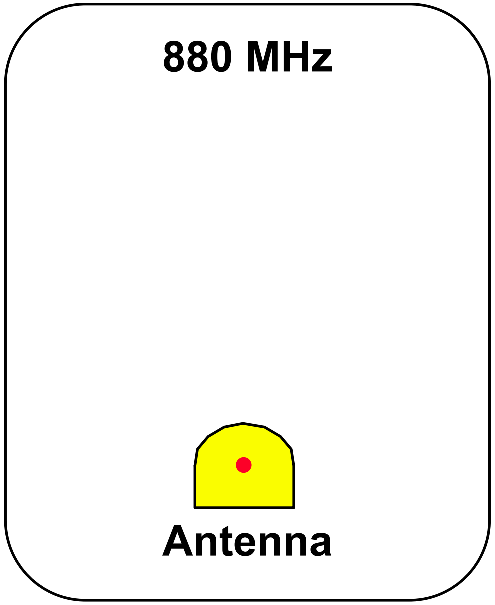
Conductive (metallic) obstruction in the path of transmit and/or receive antennas may distort antenna radiation patterns in a way that causes systems coverage problems and degradation of communications services.

A few basic precautions will prevent pattern distortions.

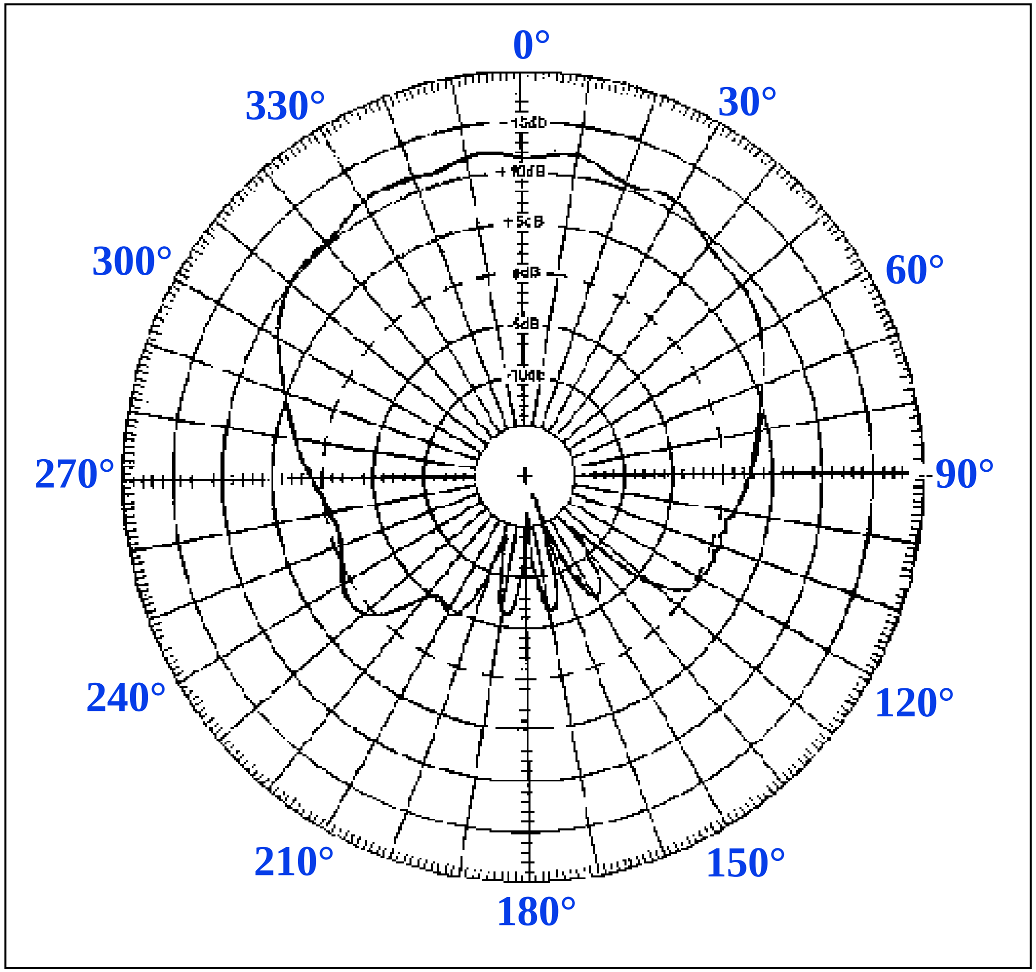
105° Horizontal Pattern

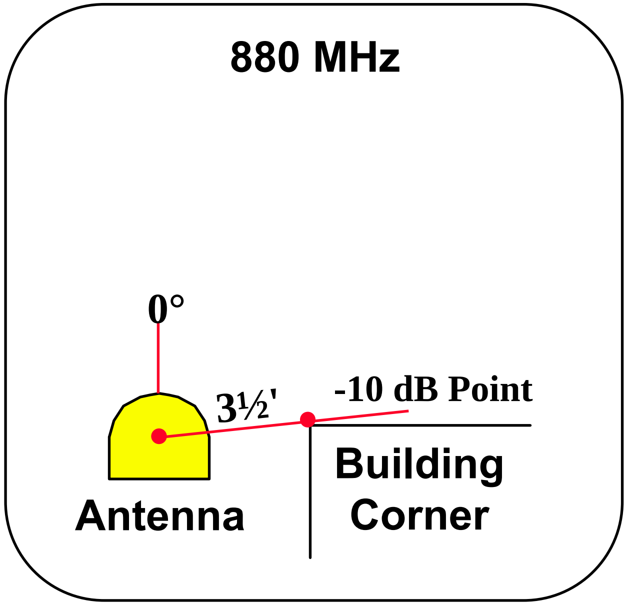
No Obstacle





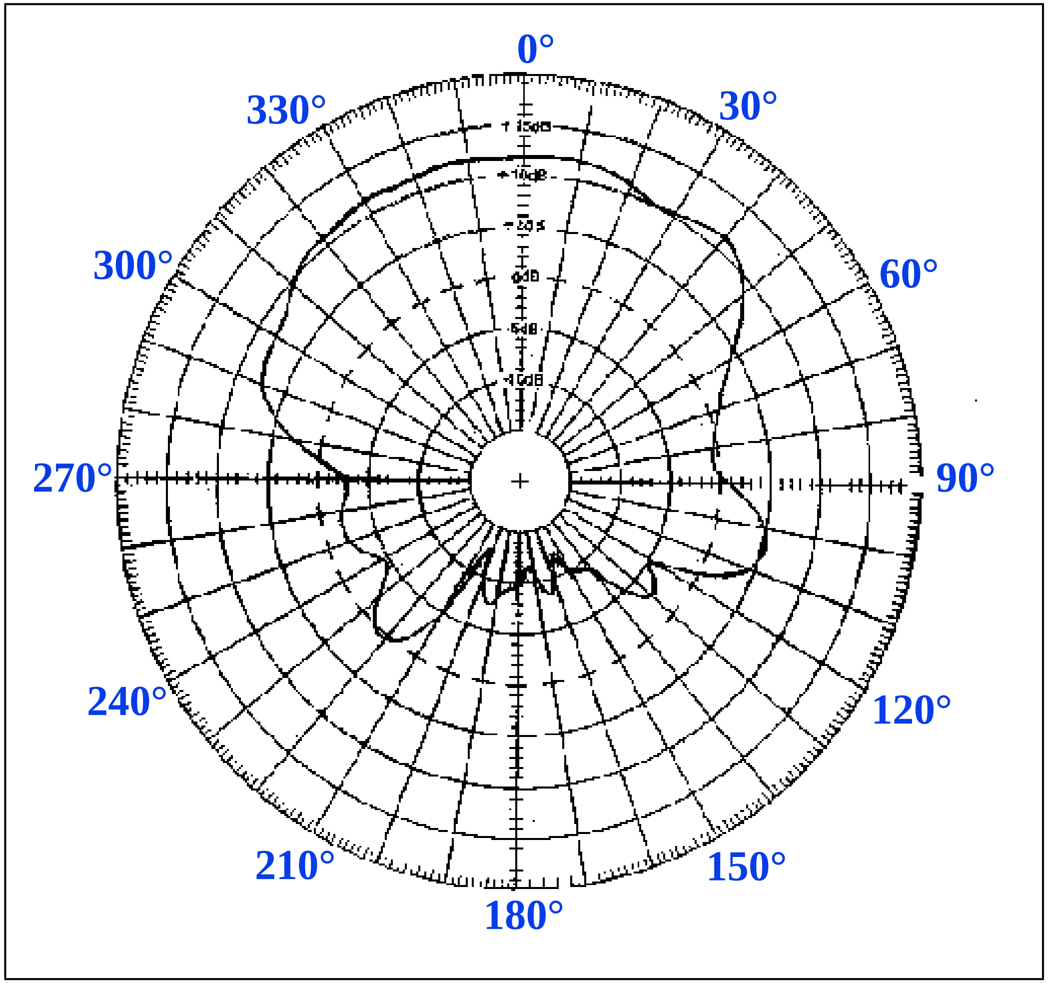
105° Horizontal Pattern
Obstruction at -10 dB Point

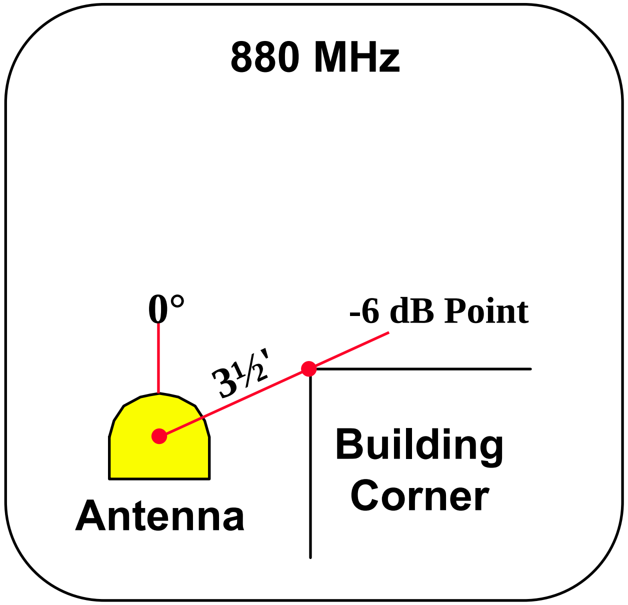




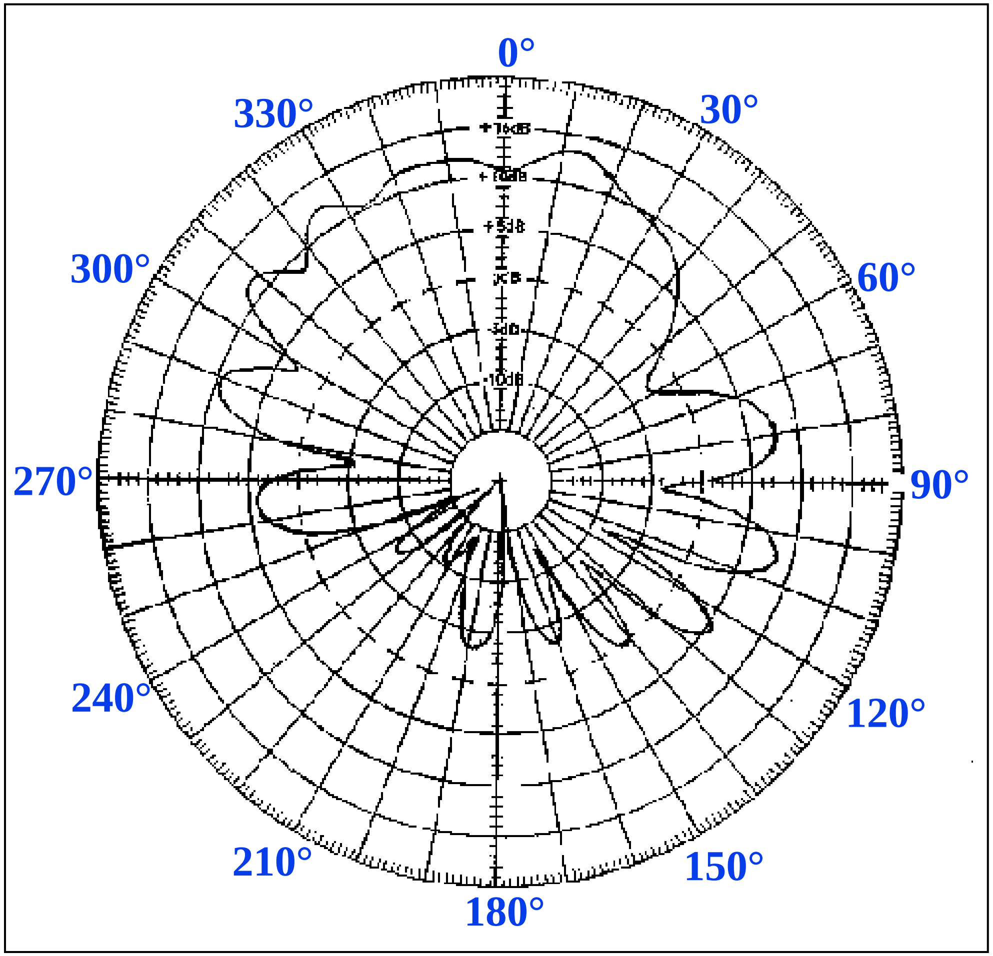
105° Horizontal Pattern

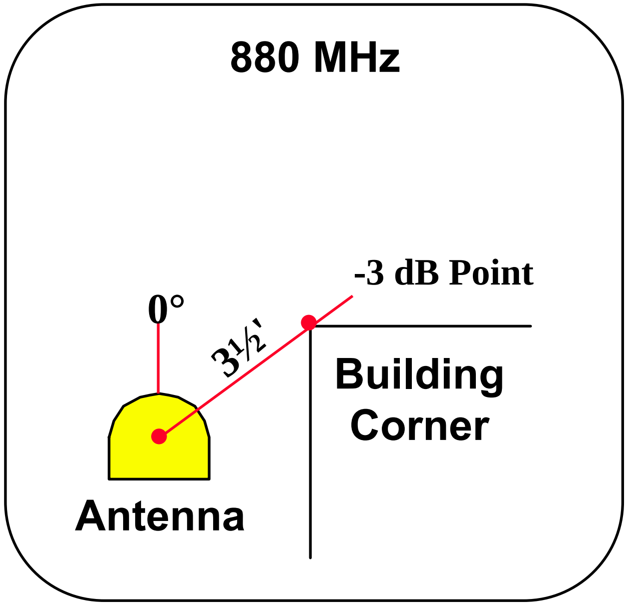
Obstruction at -6 dB Point





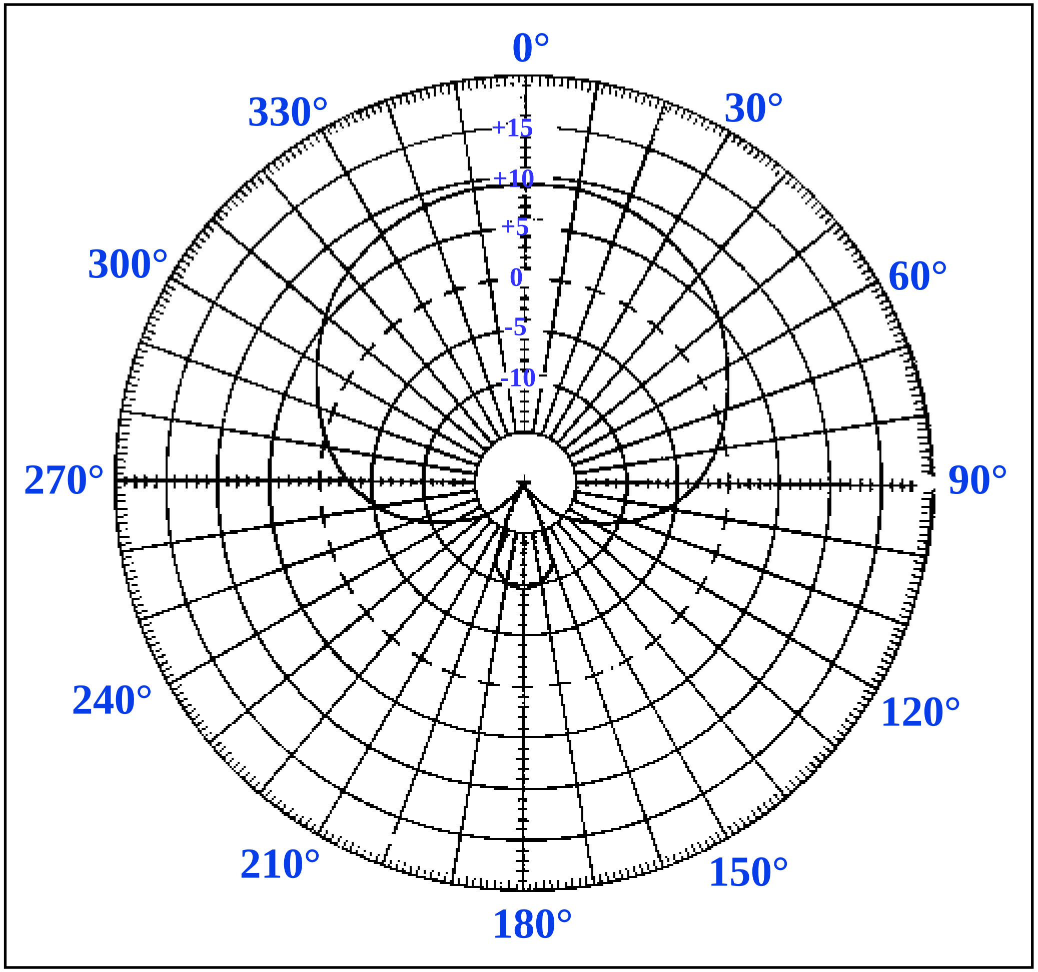
105° Horizontal Pattern
Obstruction at -3 dB Point

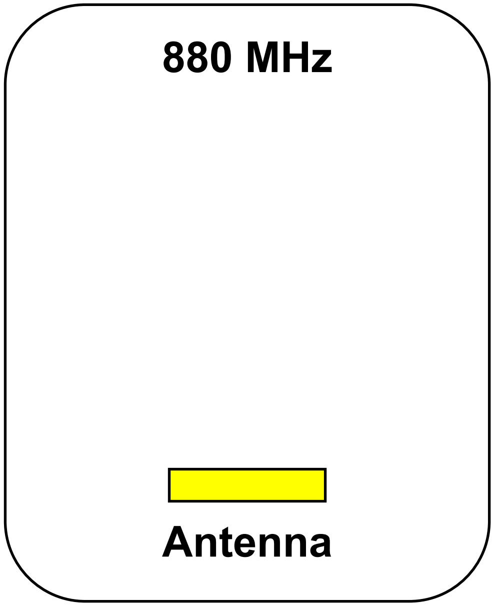




90° Horizontal Pattern

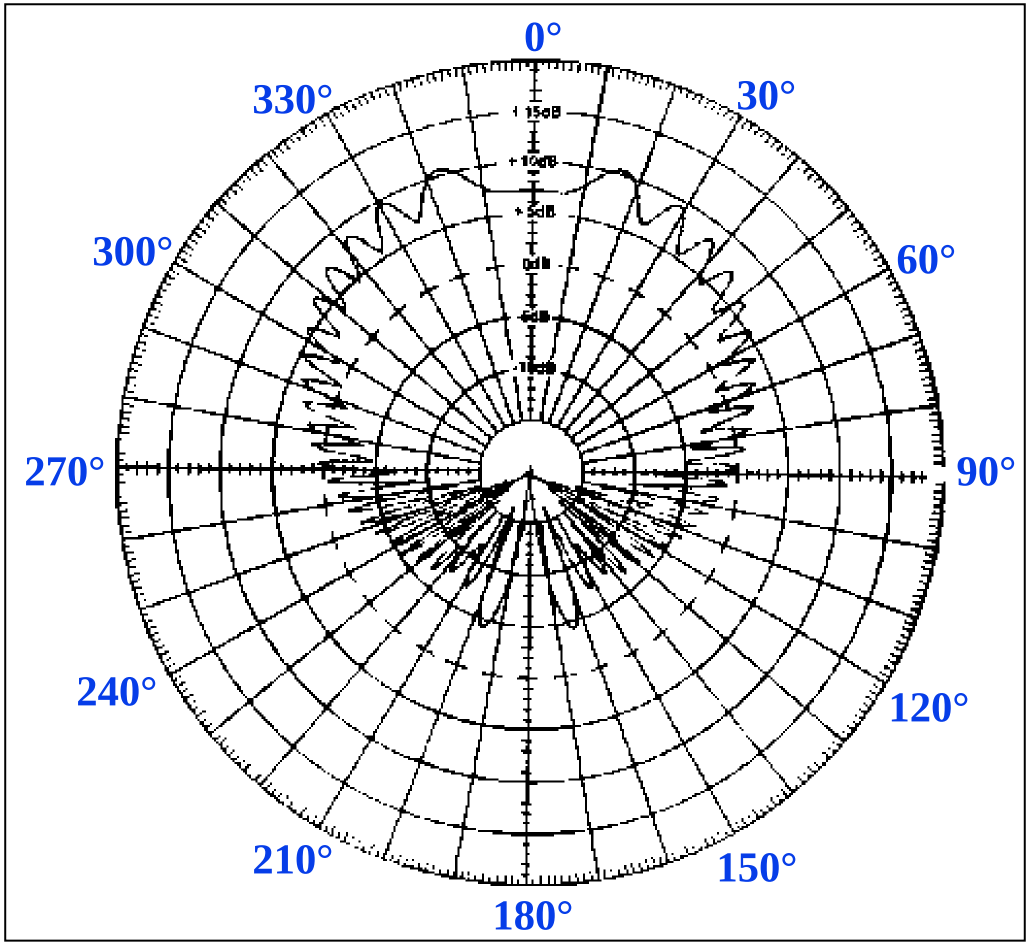
No Obstacle

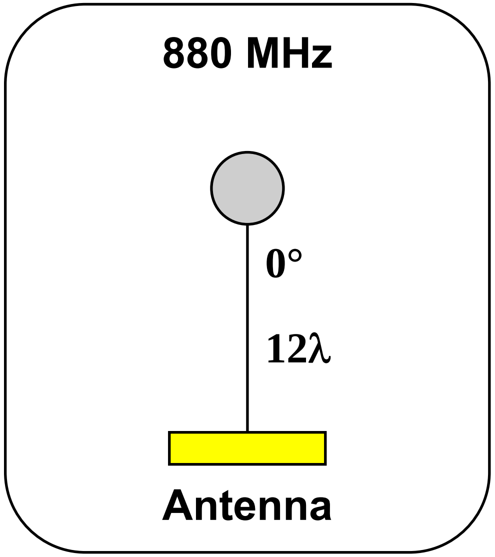




90° Horizontal Pattern

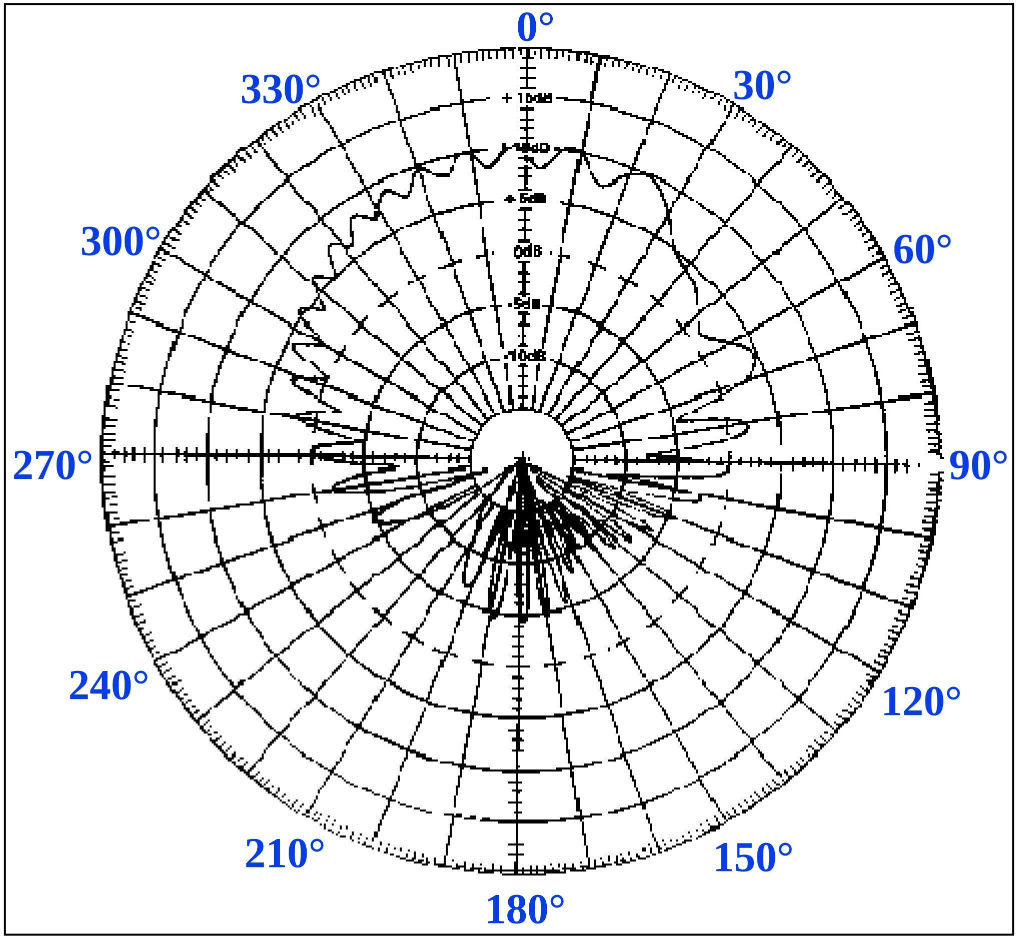
0.5 l Diameter Obstacle at 0°

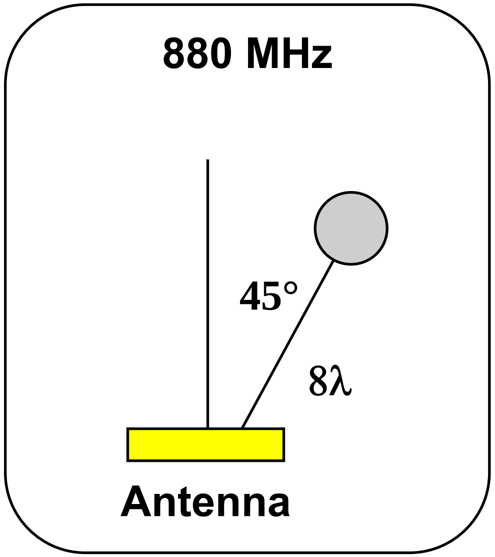




90° Horizontal Pattern

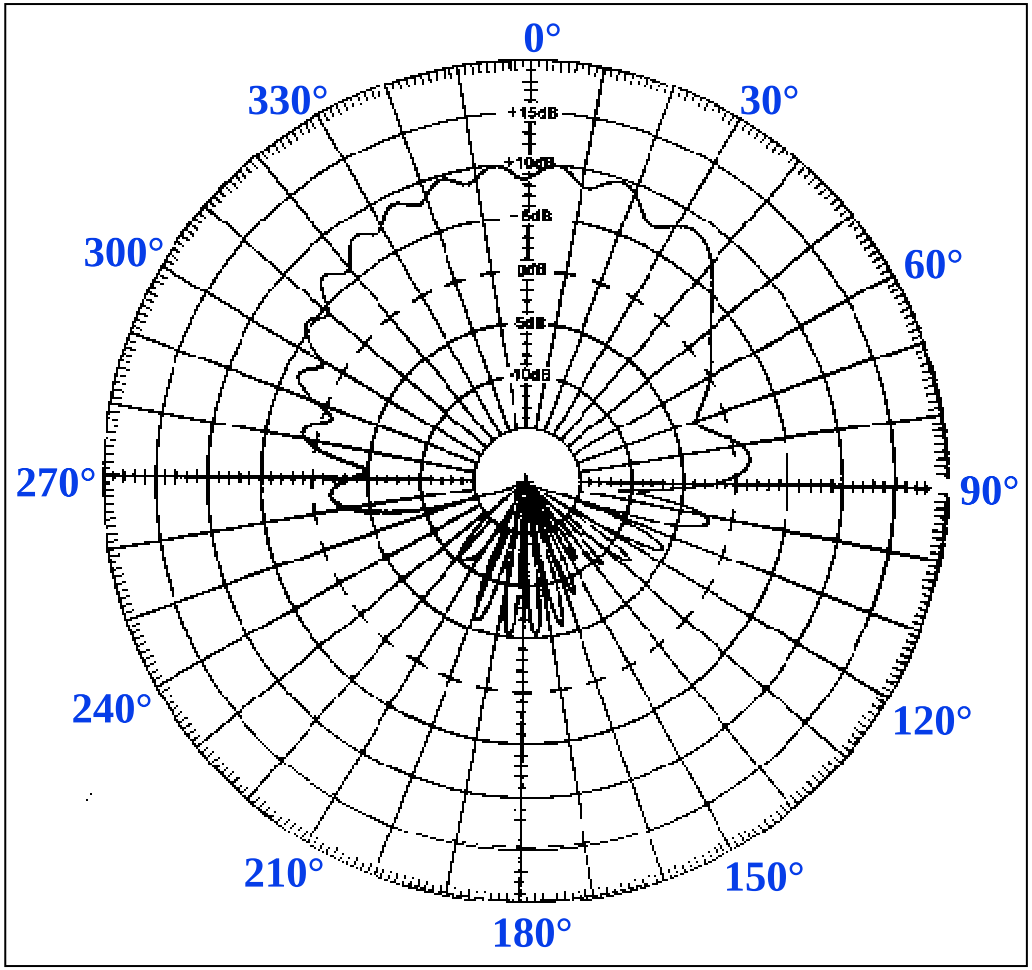
0.5 l Diameter Obstacle at 45°

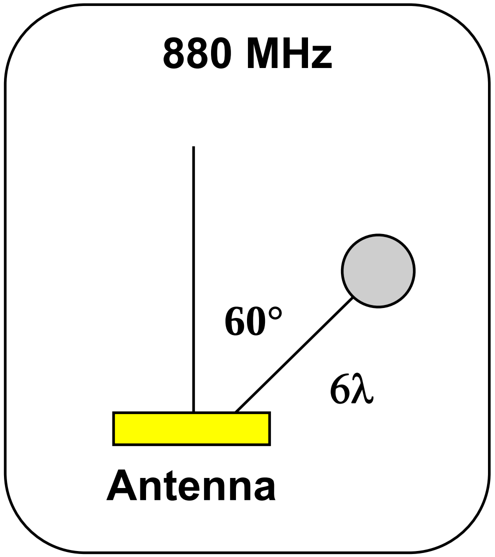




90° Horizontal Pattern

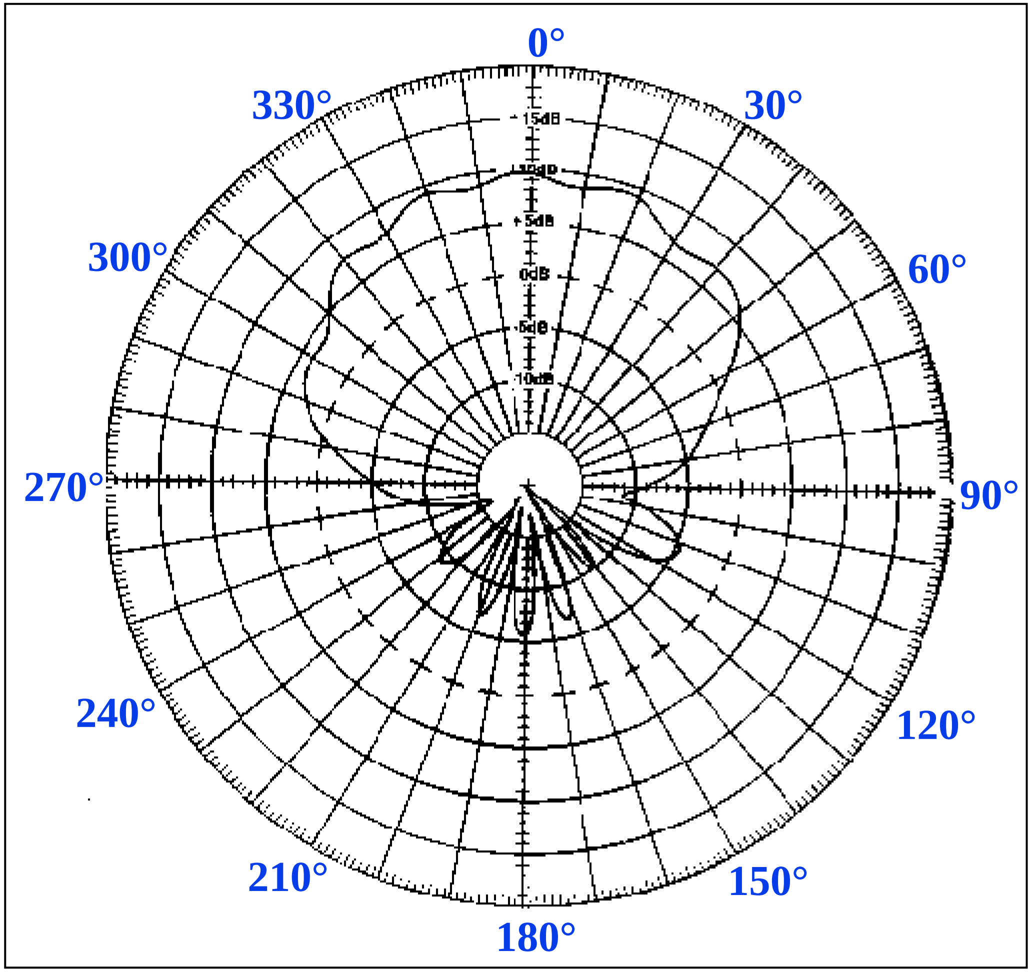
0.5 l Diameter Obstacle at 60°

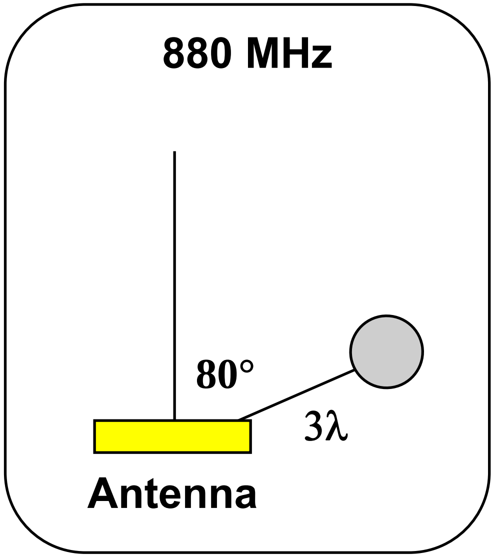




90° Horizontal Pattern

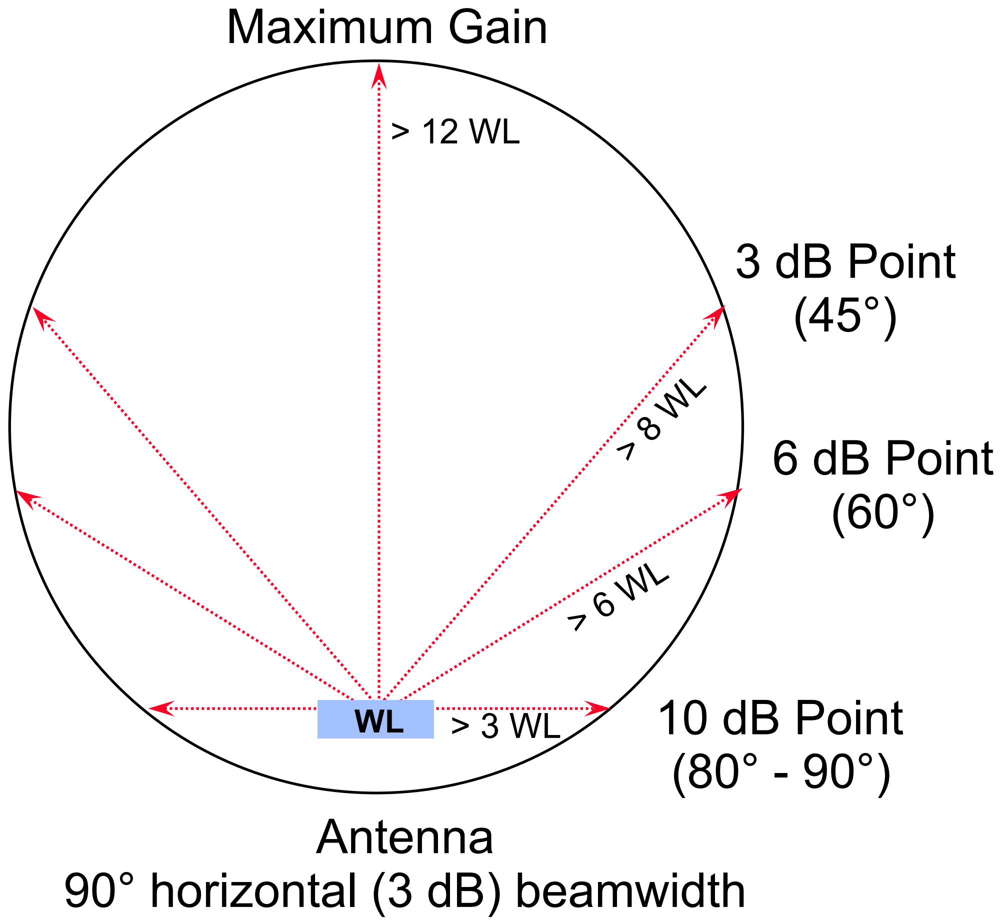
0.5 l Diameter Obstacle at 80°



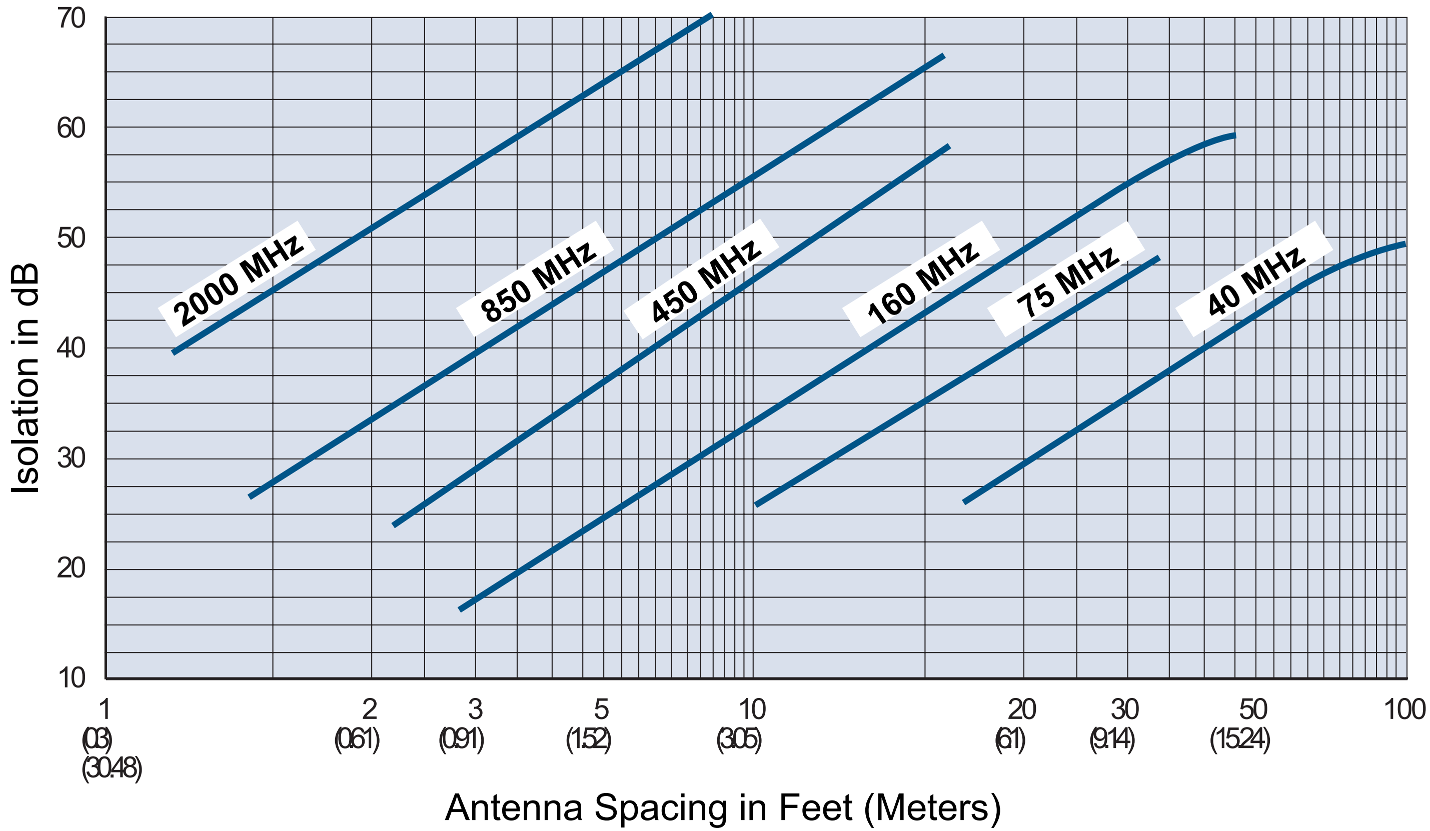


General Rule

Area that needs to be free of obstructions (> 0.57 WL)

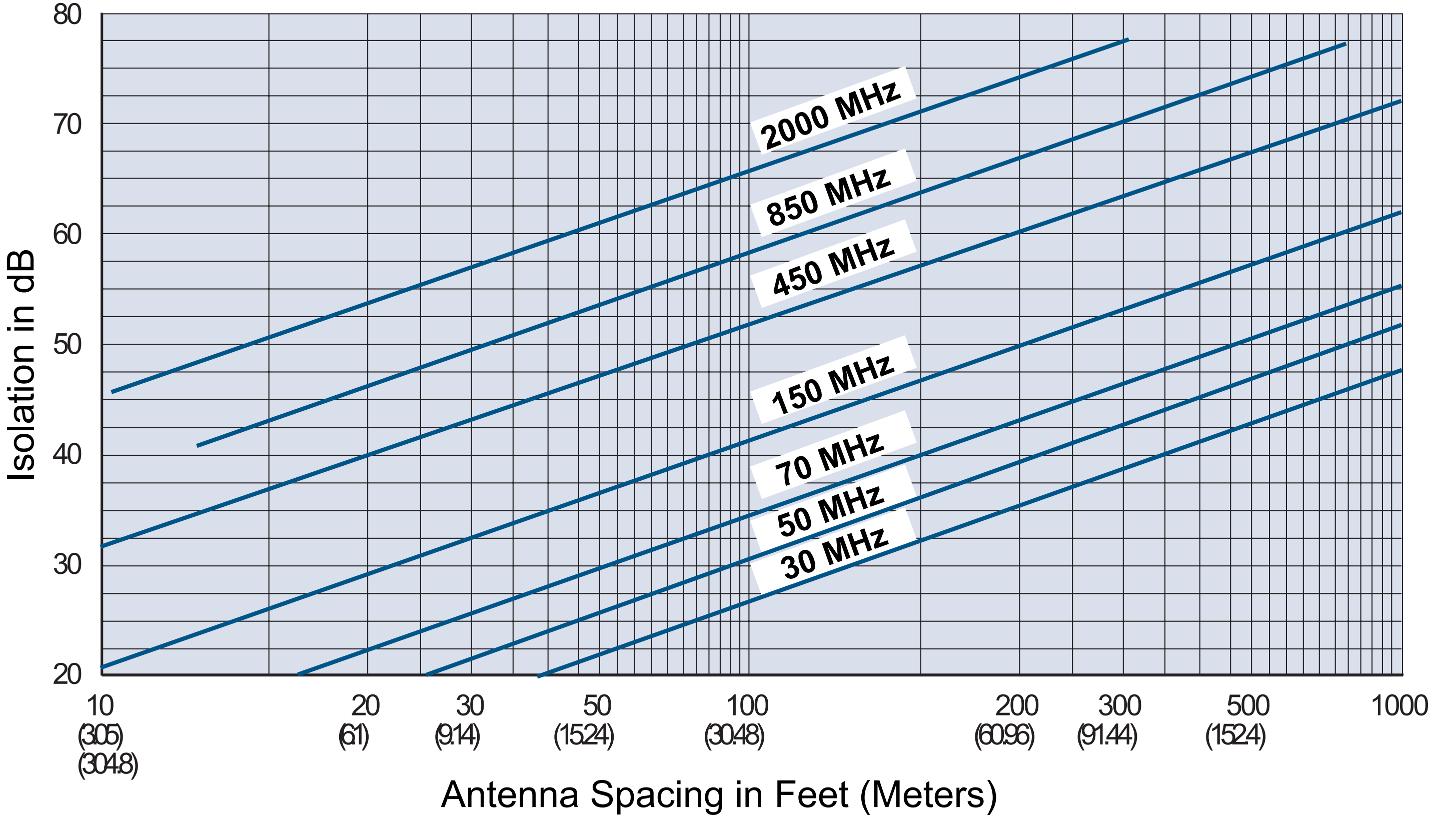


Attenuation Provided By Vertical Separation of Dipole Antennas



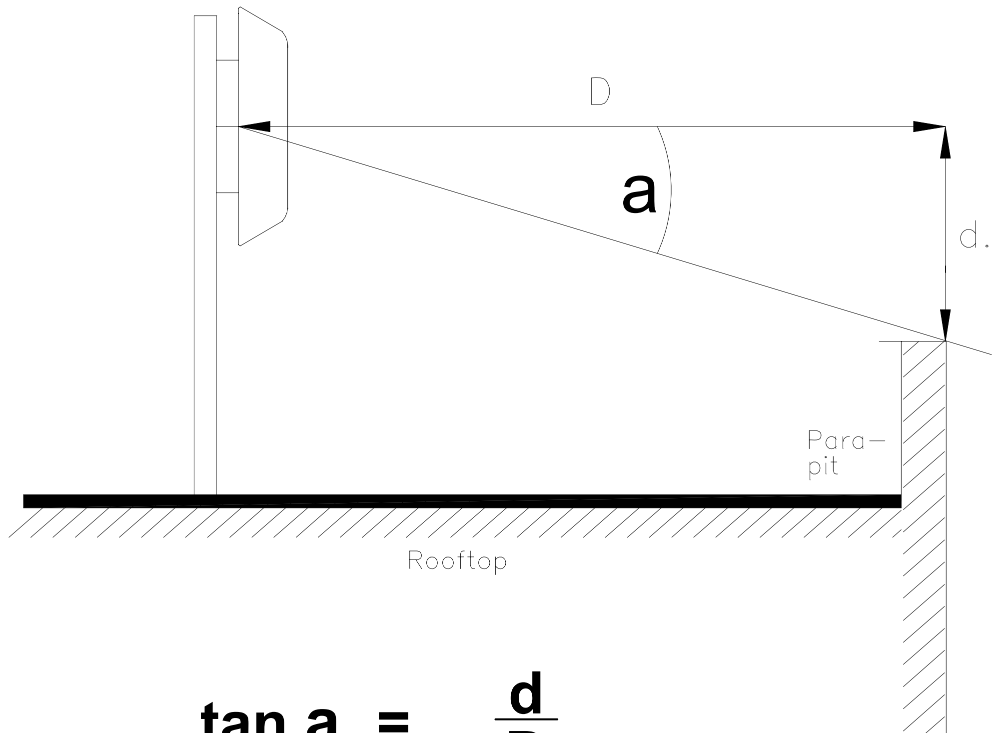
The values indicated by these curves are approximate because of coupling which exists between the antenna and transmission line. Curves are based on the use of half-wave dipole antennas. The curves will also provide acceptable results for gain type antennas. Values are measured between the physical center of the tower antennas and the antennas are mounted directly above the other, with no horizontal offset (collinear). No correction factor is required for the antenna gains.

Attenuation Provided By Horizontal Separation of Dipole Antennas



Curves are based on the use of half-wave dipole antennas. The curves will also provide acceptable results for gain type antennas if (1) the indicated isolation is reduced by the sum of the antenna gains and (2) the spacing between the gain antennas is at least 50 ft. (15.24 m) (approximately the far field).

Pattern Distortions



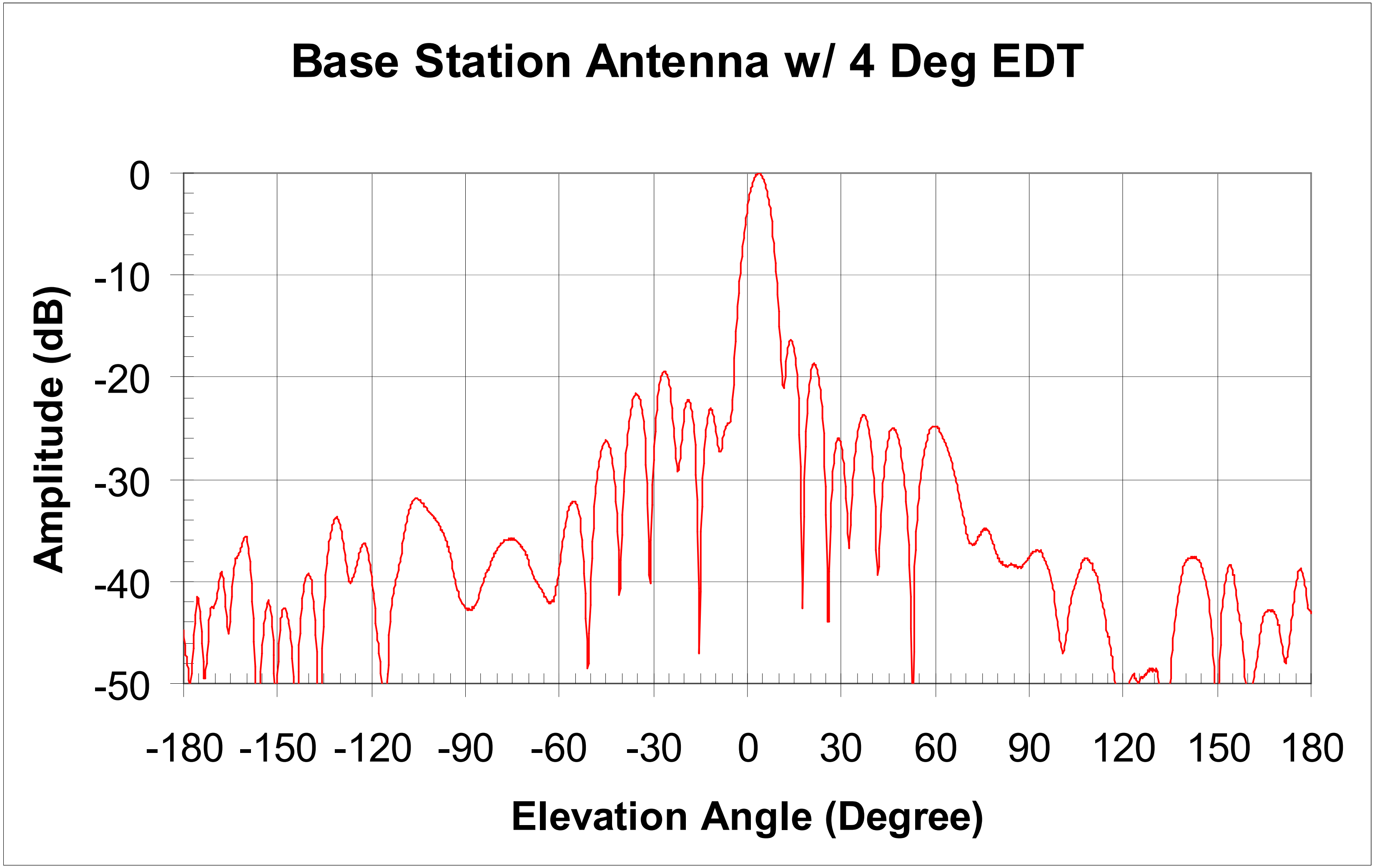
$$\tan a = \frac{d}{D}$$

$$d = D * \tan a$$

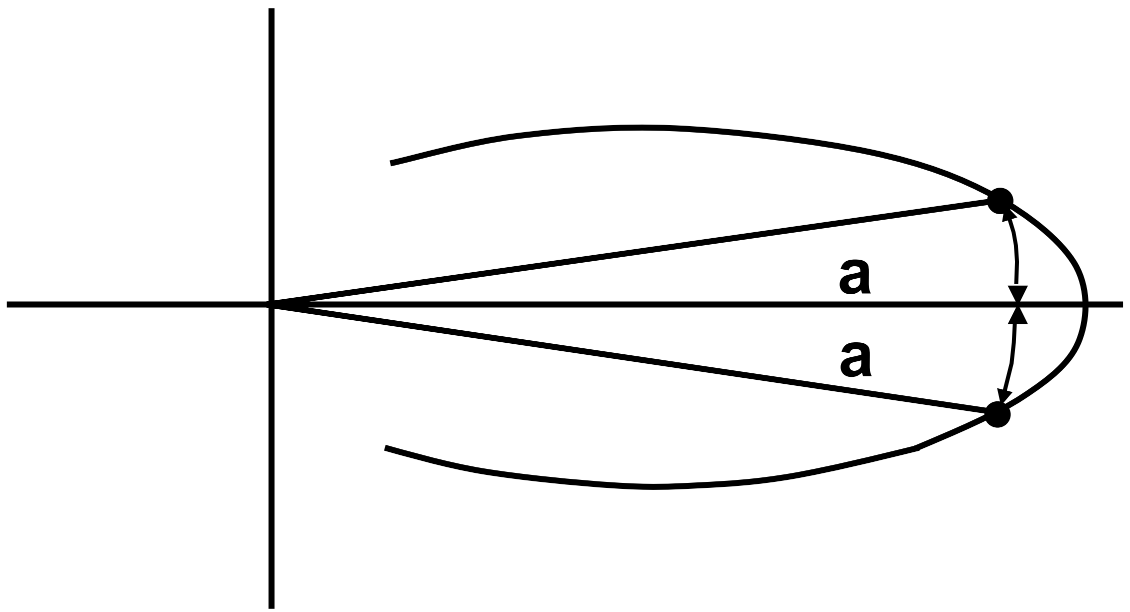
$$\tan 1° = 0.01745$$

Note: $\tan 10° = 0.1763$ $10 * 0.01745 = 0.1745$

Antenna Elevation Pattern



Gain Points of a Typical Main Lobe
(Relative to Maximum Gain)



Vertical Beam Width= 2 a (-3dB point)

-3dB point a° below bore sight.

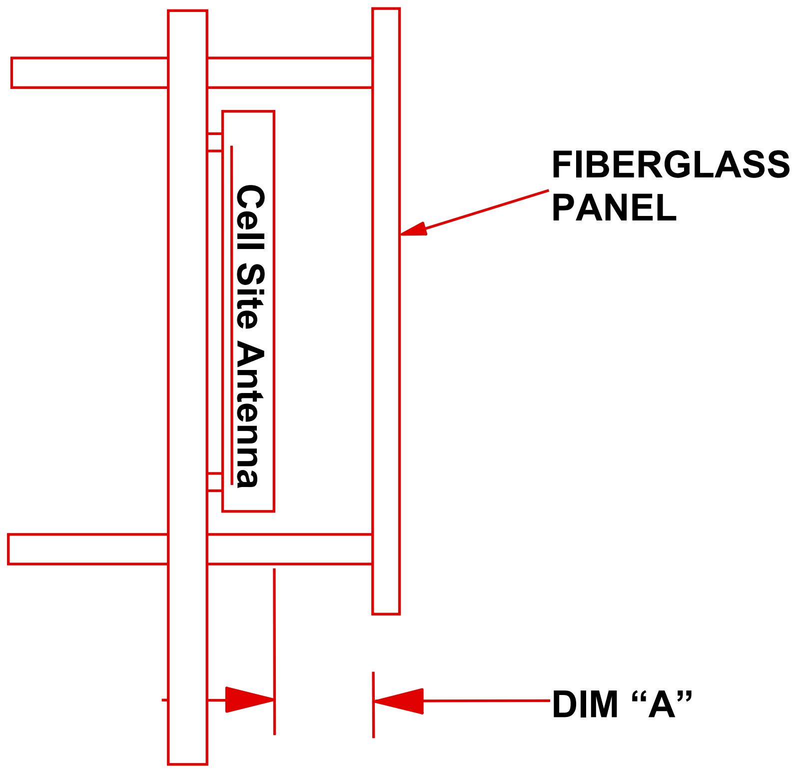
-6dB point 1.35 * a° below bore sight.

-10 dB point 1.7 * a° below bore sight.

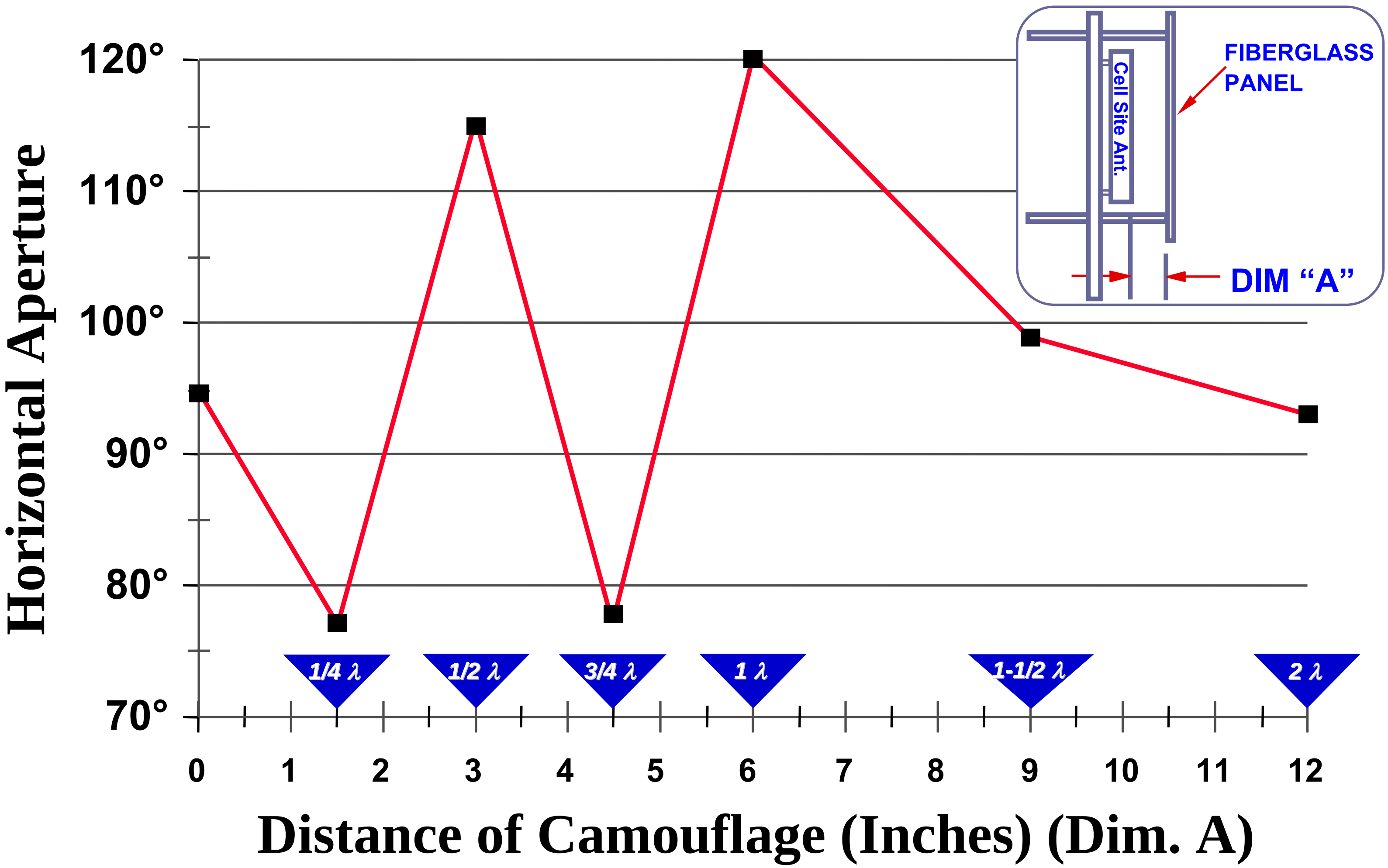
Changes In Antenna Performance

In The Presence of:

Non-Conductive Obstructions, such as Screens

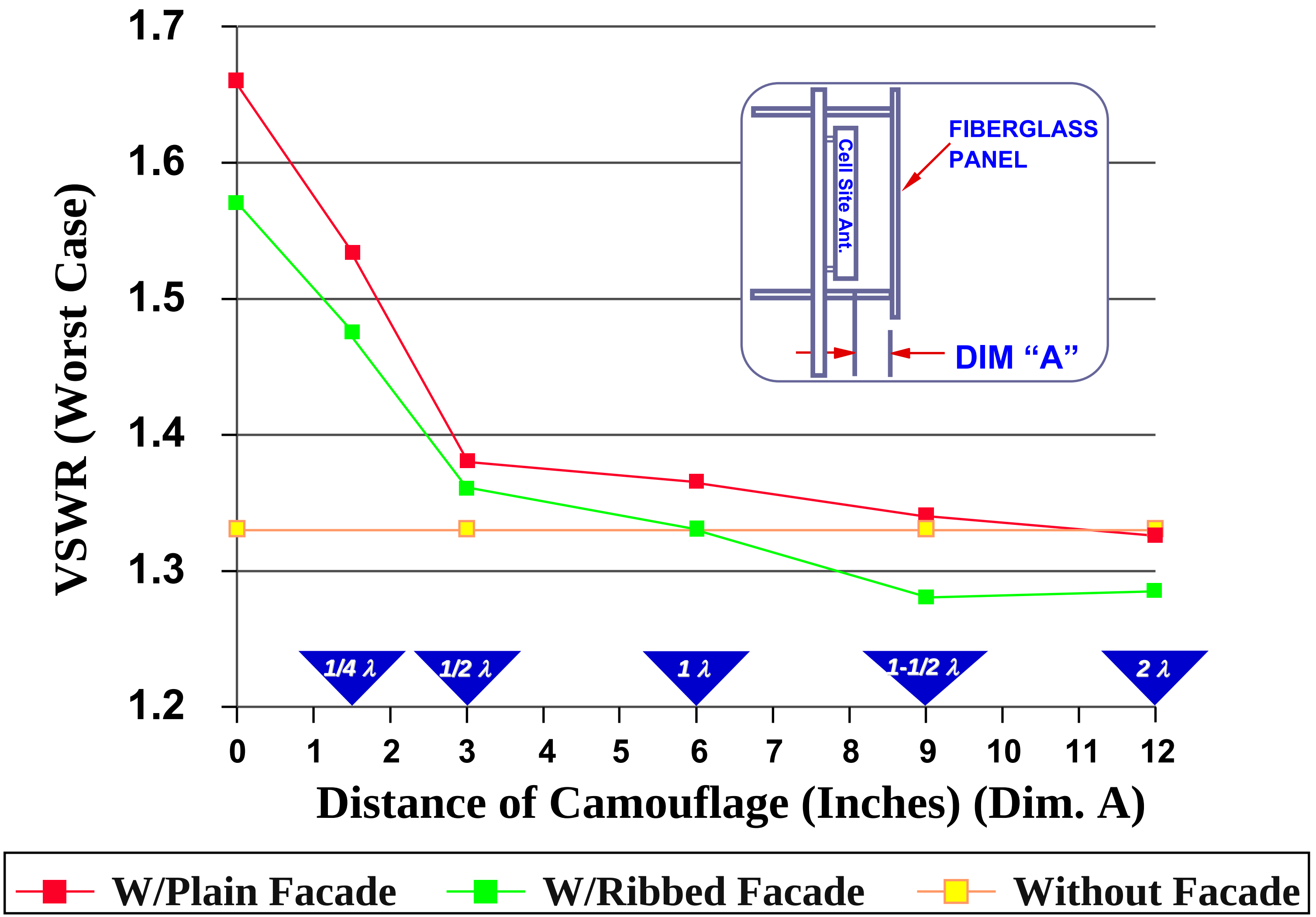


Performance of Sample PCS Antenna
Behind Camouflage (¼" Fiberglass)

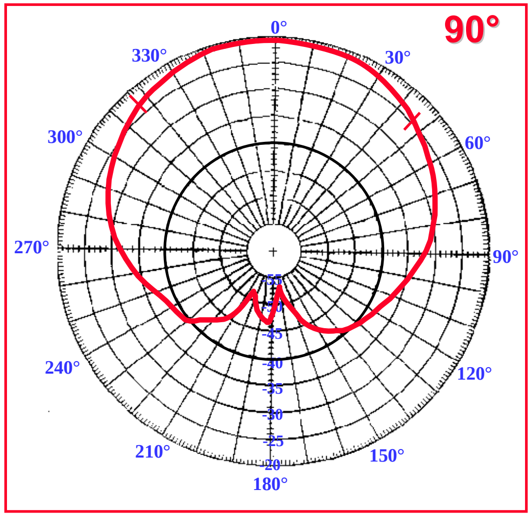


Performance of Sample PCS Antenna

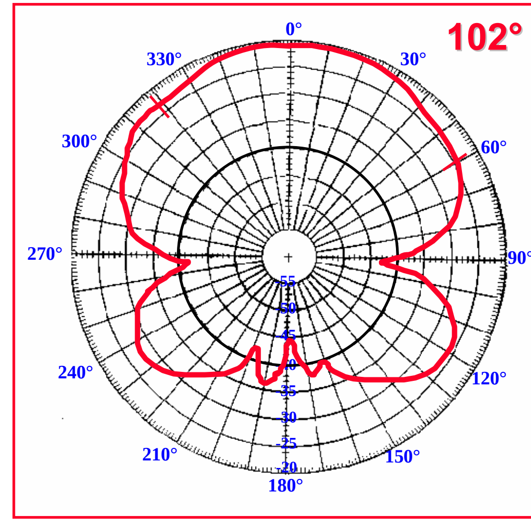
Behind Camouflage (¼" Fiberglass)



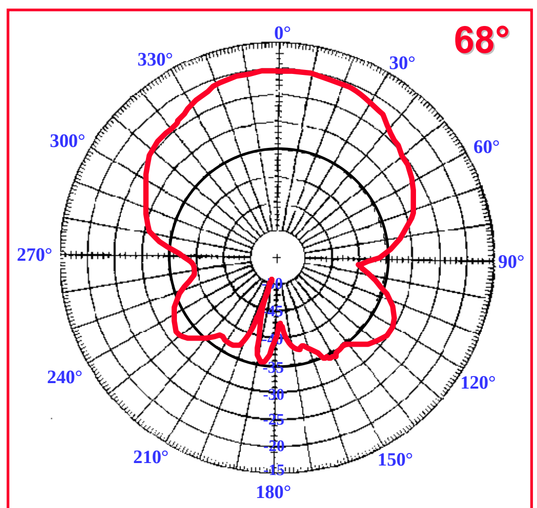
Distance From Fiberglass



No Fiberglass

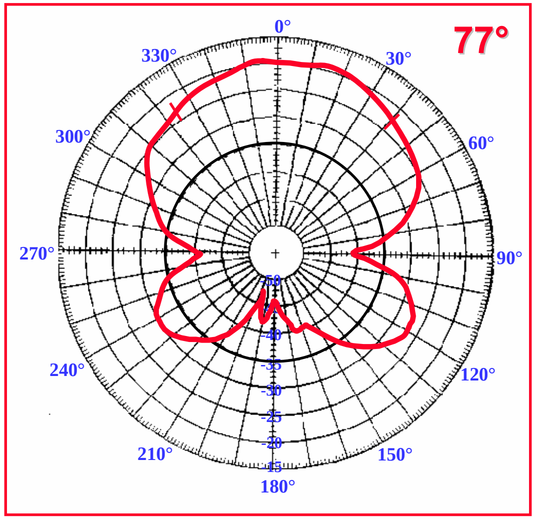


3" to Fiberglass

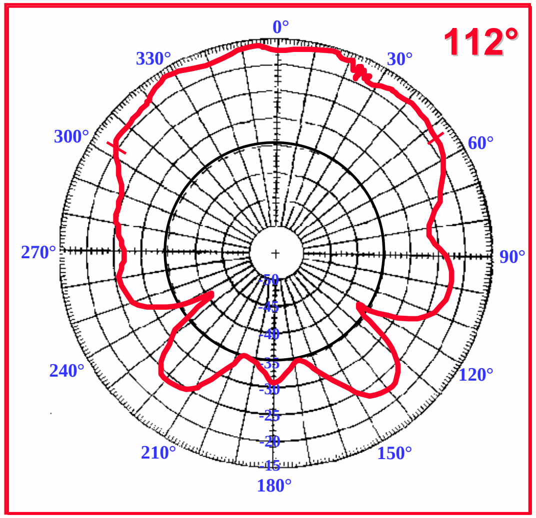


1.5" to Fiberglass

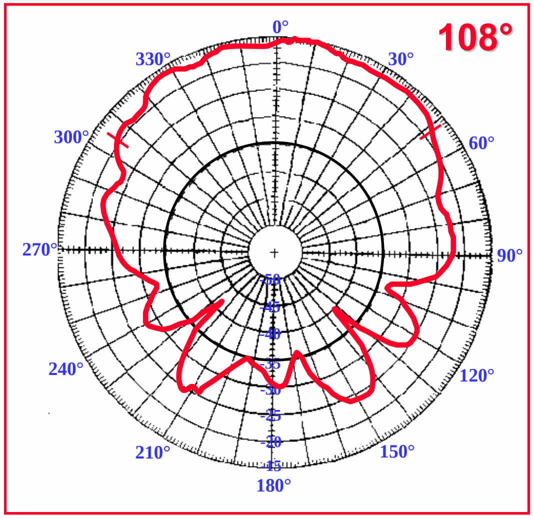
Distance From Fiberglass



4" to Fiberglass



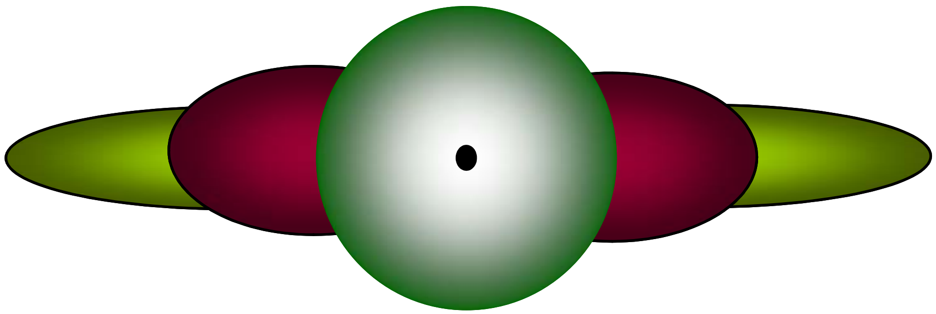
6" to Fiberglass



9" to Fiberglass

Basic Principles For base station Antenna systems

Antenna Theory



By

Amir Miraj, Senior Engineer,

Base Station Antenna Technology Evolution

Antenna Core Technology

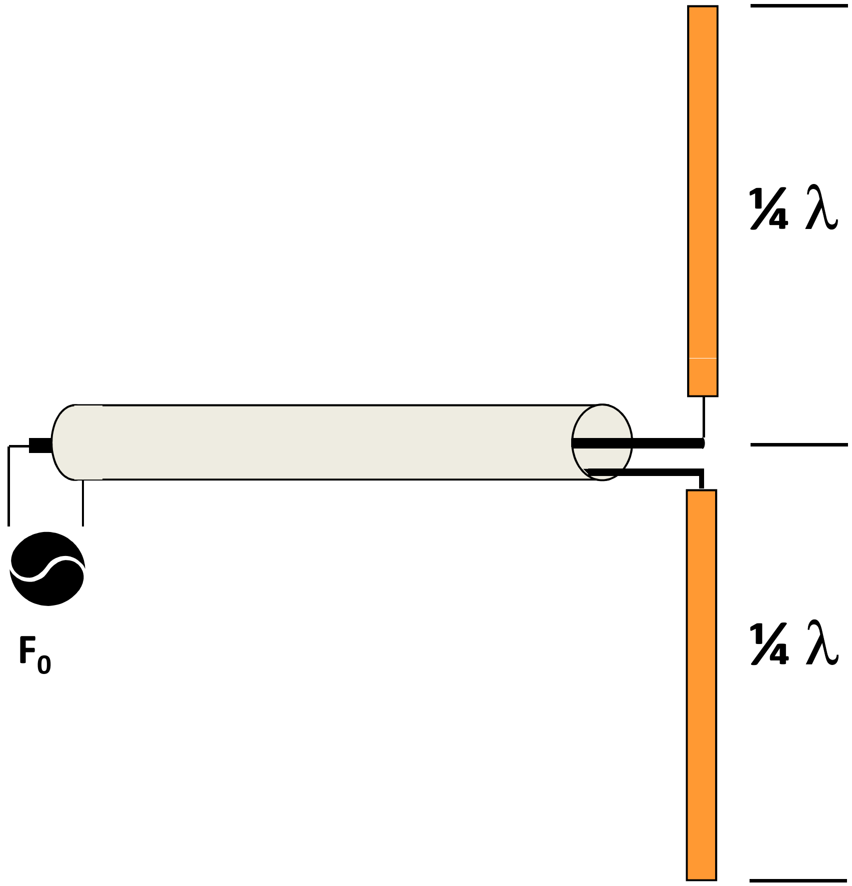
	Omni Directional	Vertical Polarization	DualPol® MIMO	DualPol® RET Interference Reduction MIMO	Dual Band Capacity Improvement with Frequency MIMO	Digital Beam Former SDMA Capacity	SmartBeam® Capacity" Load Balance MIMO

Air Interfaces

Dominate Application · Significant Application · Low Application

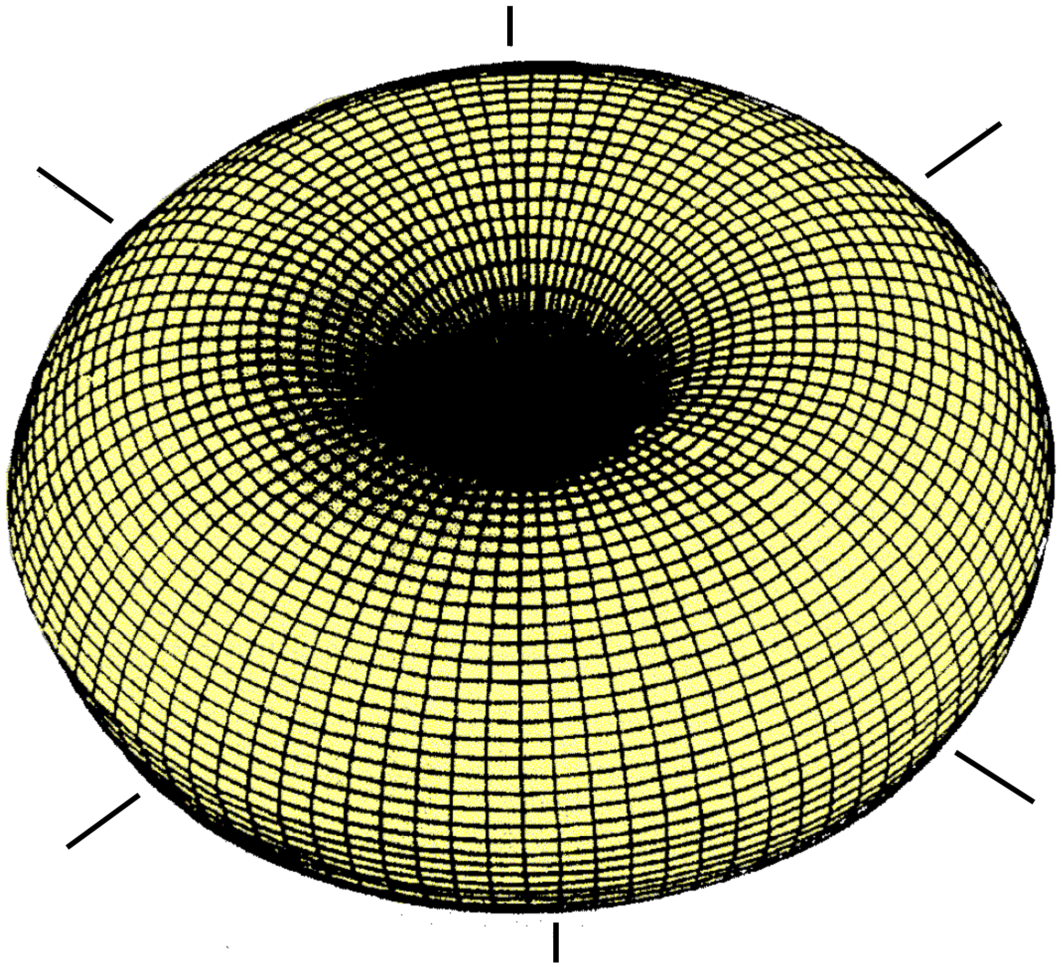
Air Interfaces	Omni Directional	Vertical Polarization	DualPol® MIMO	DualPol® RET Interference Reduction MIMO	Dual Band Capacity Improvement with Frequency MIMO	Digital Beam Former SDMA Capacity	SmartBeam® Capacity" Load Balance MIMO
AMPS	Dominate	Dominate	Low	Low	Low	Low	Low
GSM	Significant	Low	Dominate	Dominate	Significant	Low	Significant
CDMA	Low	Significant	Significant	Significant	Low	Low	Significant
W-CDMA	Low	Low	Low	Dominate	Dominate	Low	Significant
WiMAX	Low	Low	Dominate	Significant	Significant	Significant	Significant
TD-SCDMA	Low	Low	Low	Low	Low	Dominate	Low
LTE	Low	Low	Low	Dominate	Significant	Significant	Dominate

Dipole



F_0 (MHz)	λ (Meters)	λ (Inches)
30	10.0	393.6
80	3.75	147.6
160	1.87	73.8
280	1.07	42.2
460	0.65	25.7
800	0.38	14.8
960	0.31	12.3
1700	0.18	6.95
2000	0.15	5.9

3D View Antenna Pattern



Source: COMSEARCH

Understanding The Mysterious "dB"

dBd	Signal strength relative to a ***dipole*** in empty space
dBi	Signal strength relative to an ***isotropic*** radiator
dB	***Difference*** between two signal strengths
dBm	Absolute signal strength relative to 1 milliwatt 1 mWatt = 0 dBm 1 Watt = 30 dBm 20 Watts = 43 dBm Note: The Logarithmic Scale $10 * \log_{10}$ (Power Ratio)
dBc	Signal strength ***relative*** to a signal of known strength, in this case: the ***carrier*** signal Example: –150 dBc = 150 dB below carrier signal If two carriers are 20 Watt each = 43 dBm –150 dBc = –107 dBm or ~0.02 pWatt or ~1 microvolt

Effect Of VSWR

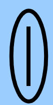
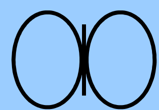
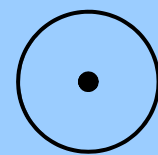
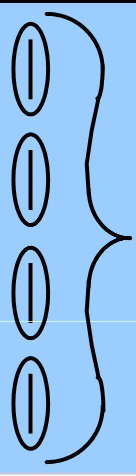
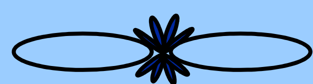
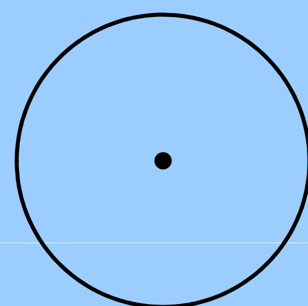
Good VSWR is only one component of an efficient antenna.

VSWR	Return Loss (dB)	Transmission Loss (dB)	Power Reflected (%)	Power Trans. (%)
1.00	∞	0.00	0.0	100.0
1.10	26.4	0.01	0.2	99.8
1.20	20.8	0.04	0.8	99.2
1.30	17.7	0.08	1.7	98.3
1.40	15.6	0.12	2.8	97.2
1.50	14.0	0.18	4.0	96.0
2.00	9.5	0.51	11.1	88.9

Shaping Antenna Patterns

Vertical arrangement of properly phased dipoles allows control of radiation patterns at the horizon as well as above and below the horizon. The more dipoles that are stacked vertically, the flatter the vertical pattern is and the higher the antenna coverage or ‘gain’ is in the general direction of the horizon.

aping Antenna Patterns (Continued)

Aperture of Dipoles	Vertical Pattern	Horizontal Pattern
	 Single Dipole	
	 4 Dipoles Vertically Stacked	

- Stacking 4 dipoles vertically in line changes the pattern shape (squashes the doughnut) and increases the gain over single dipole.
- The peak of the horizontal or vertical pattern measures the gain.
- The little lobes, illustrated in the lower section, are secondary minor lobes.

- General Stacking Rule
- Collinear elements (in-line vertically).
- Optimum spacing (for non-electrical tilt) is approximately 0.9λ.
- Doubling the number of elements increases gain by 3 dB, and reduces vertical beamwidth by half.

Gain

What is it?

Antenna gain is a comparison of the power/field characteristics of a device under test (DUT) to a specified gain standard.

Why is it useful?

Gain can be associated with coverage distance and/or obstacle penetration (buildings, foliage, etc).

How is it measured?

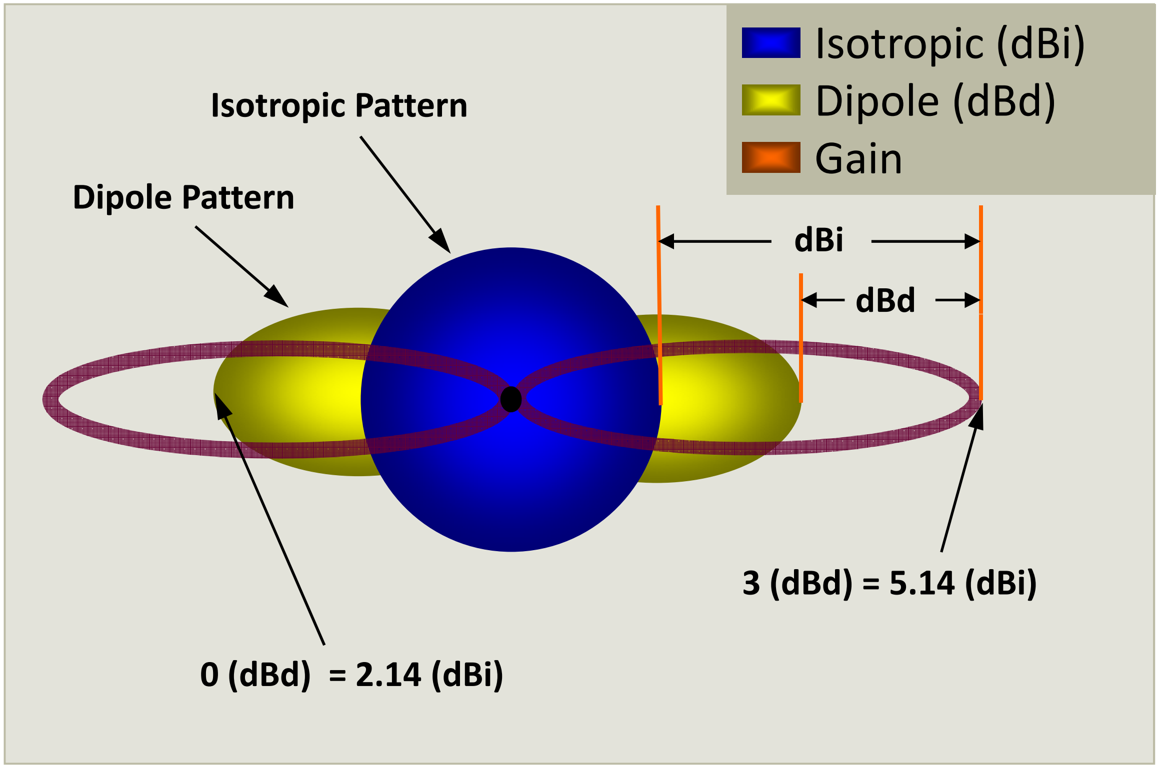
It is measured using data collected from antenna range testing. The reference gain standard must always be specified.

What is Andrew standard?

Andrew conforms to the industry standard of +/–1 dB accuracy.

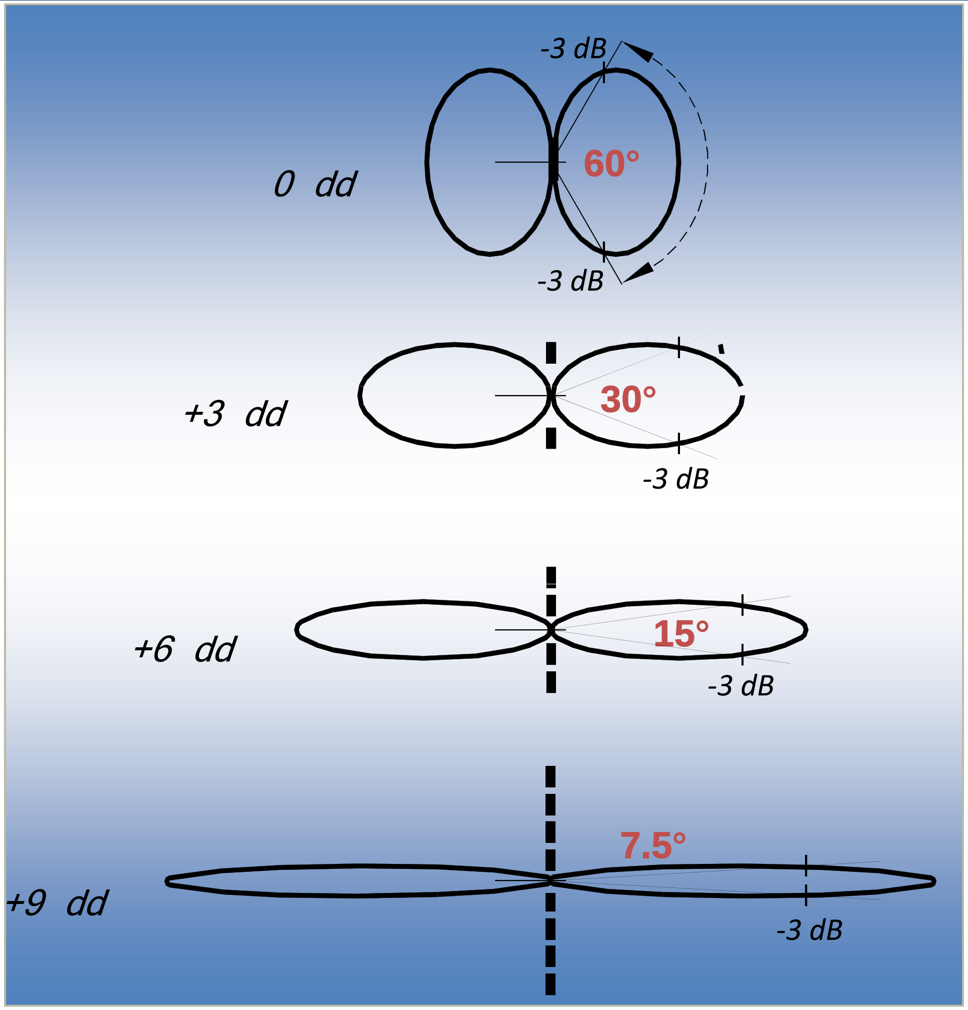
Gain References (dBd And dBi)

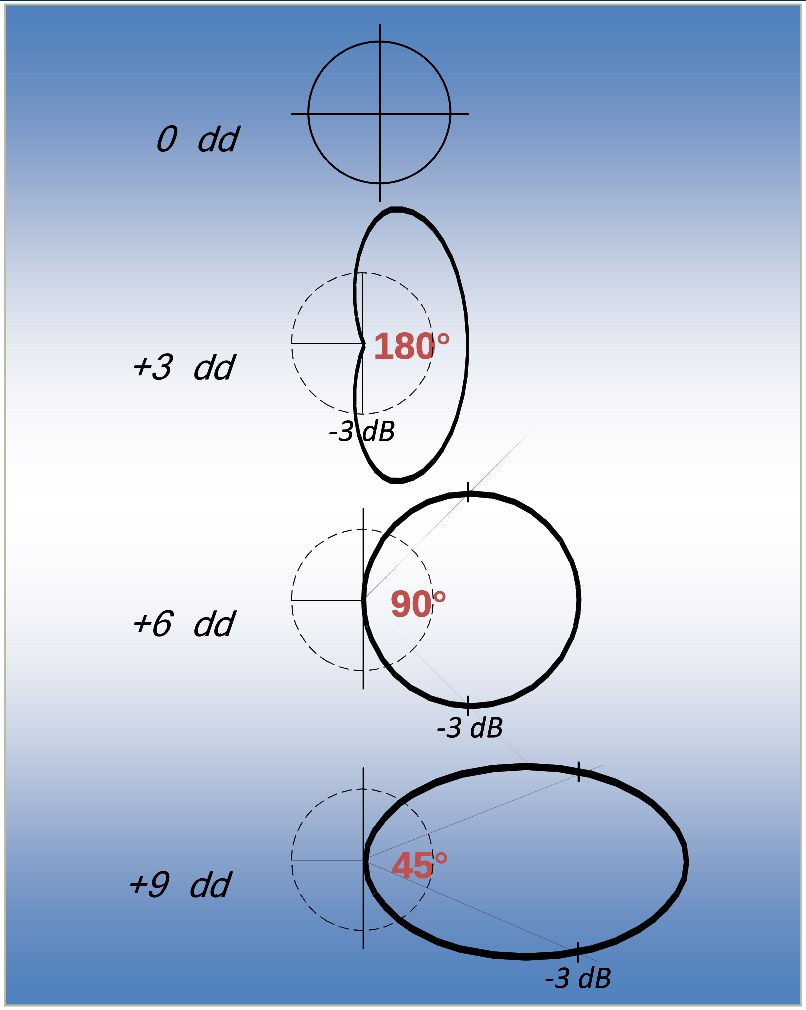
- An isotropic antenna is a single point in space radiating in a perfect sphere (not physically possible).
- A dipole antenna is one radiating element (physically possible).
- A gain antenna is two or more radiating elements phased together.



Principles Of Antenna Gain

Omni Antenna, Side View	Directional Antennas, Top View





Theoretical Gain Of Antennas (dBd)

# of Radiators Vertically Spaced (0.9λ)

	3 dB Horizontal Aperture (Influenced by Grounded Back "Plate")								Typical Length of Antenna (ft.)		
	360°	180°	120°	105°	90°	60°	45°	33°	800/900 MHz	1800/1900	Vertical Beamwidth
1	0	3	4	5	6	8	9	10.5	1	0.5	60°
2	3	6	7	8	9	11	12	13.6	2	1	30°
3	4.5	7.5	8.5	9.5	10.5	12.5	13.5	15.1	3	1.5	20°
4	6	9	10	11	12	14	15	16.6	4	2	15°
6	7.5	10.5	11.5	12.5	13.5	15.5	16.5	18.1	6	3	10°
8	9	12	13	14	15	17	18	19.6	8	4	7.5°

Could be horizontal radiator pairs for narrow horizontal apertures.

Antenna Gain

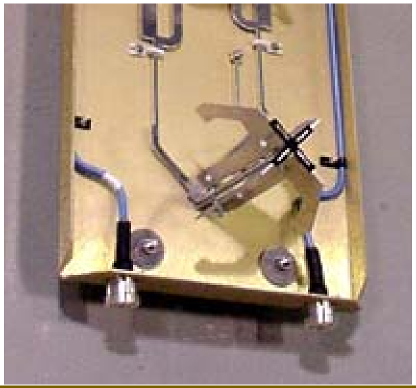
- Gain (dBi) = Directivity (dBi) – Losses (dB)
- Losses: Conductor
Dielectric
Impedance
Polarization
- Measure using ‘Gain by Comparison’

Antenna Polarization

- Vertical polarization
  - Traditional land mobile use
  - Omni antennas
  - Requires spatial separation for diversity
  - Still recommended in rural, low multipath environments
- Polarization diversity
  - Slant 45° (+ and –) is now popular
  - Requires only a single antenna for diversity
  - Lower zoning impact
  - Best performance in high and medium multipath environments

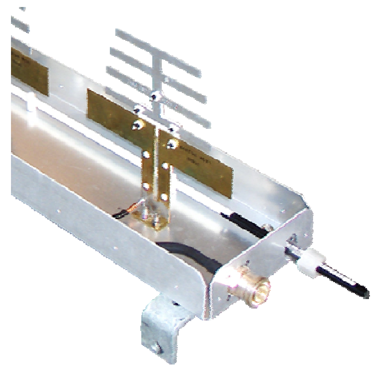
Measured data will be presented in the Systems Section

Various Radiator Designs

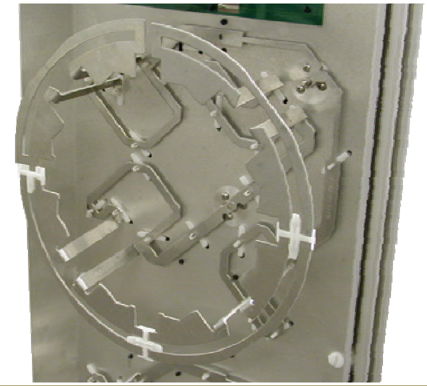


800/900 MHz DualPol®

800/900 MHz PCB DualPol®



800/900 MHz Log Periodic Vertical Pol

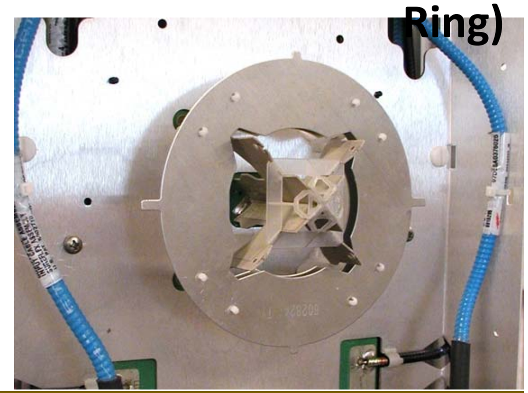


800/900 MHz DualPol® MAR (Microstrip Annular Ring)

1800/1900/UMTS DualPol® Directed Dipole

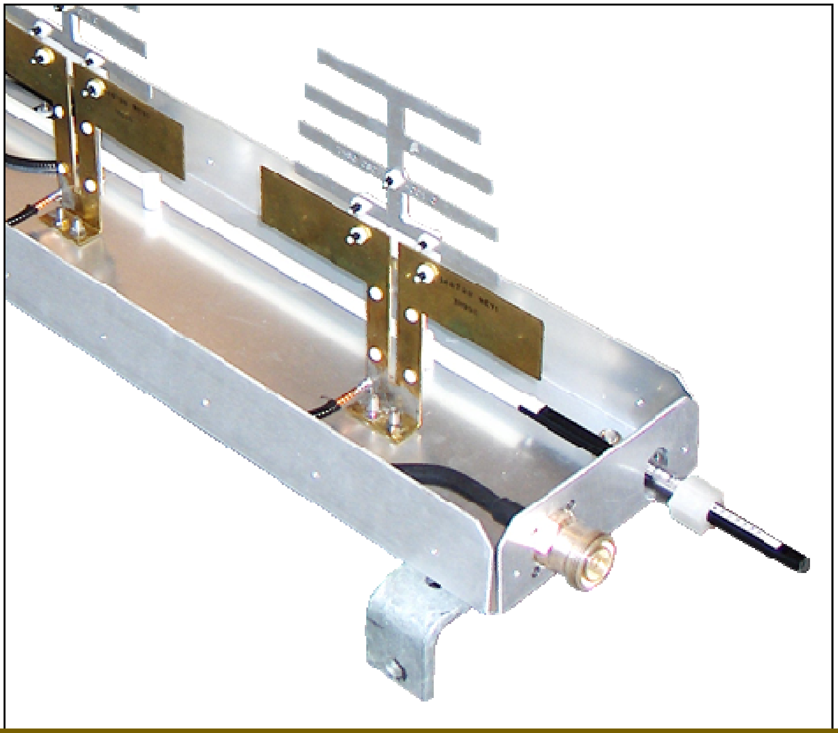
1800/1900/UMTS PCB DualPol®

1800/1900/UMTS Vertical Pol

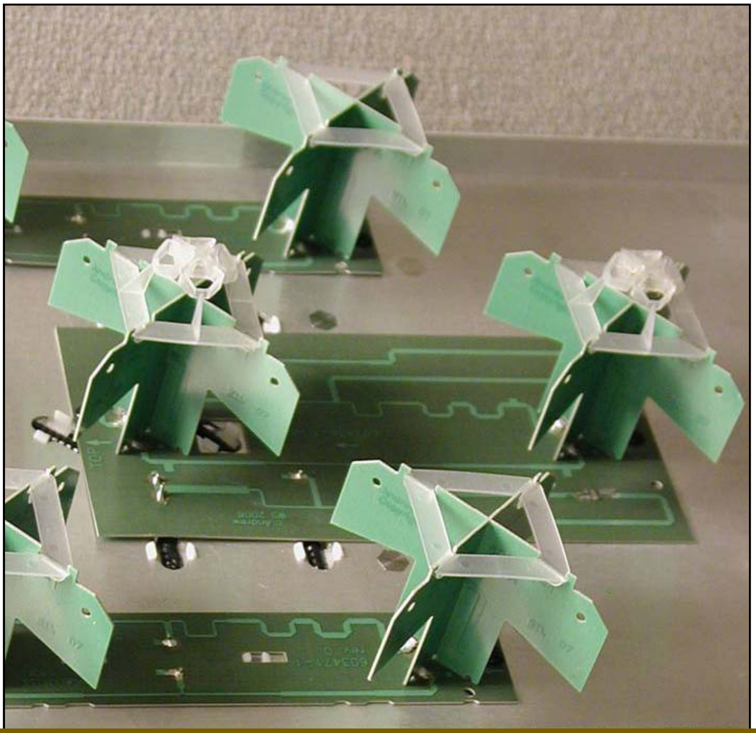


Interleaved Dual Band, DualPol® and MAR (Microstrip Annular Ring)

Antenna Basics . . .
Cross Polarized Dipoles

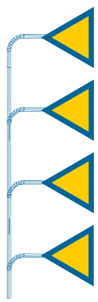
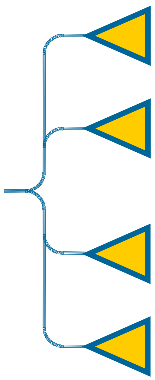
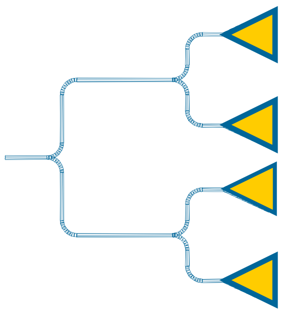


Single Vertically Polarized Dipole

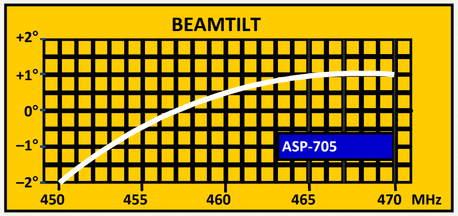


Two +/– 45° Polarized Dipoles

Feed Harness Construction

ASP705 (Old Style)	ASP705K	LBX-6513DS
		
Series Feed	**Center Feed (Hybrid)**	**Corporate Feed**

Feed Harness Construction (Continued)

	Series Feed	Center Feed (Hybrid)	Corporate Feed
Advantages	• Minimum feed losses • Simple feed system	• Frequency independent main lobe direction • Reasonably simple feed system	• Frequency independent main beam direction • More beam shaping ability, sidelobe suppression
Disadvantages		• Not as versatile as corporate (less bandwidth, less beam shaping)	• Complex feed system

Feed Networks

- Coaxial cable
  - Best isolation
  - Constant impedance
  - Constant phase
- Microstripline, corporate feeds
  - Dielectric substrate
  - Air substrate

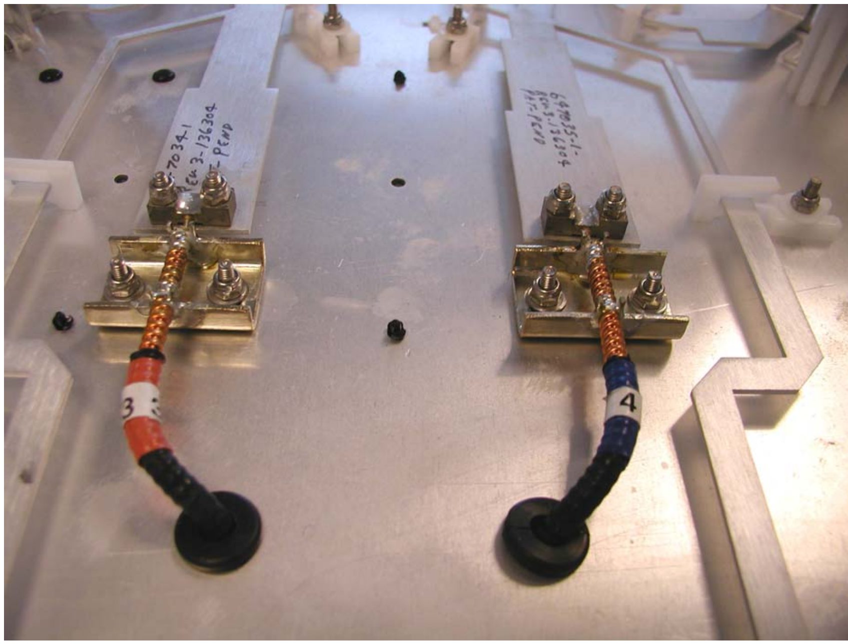
Microstrip Feed Lines

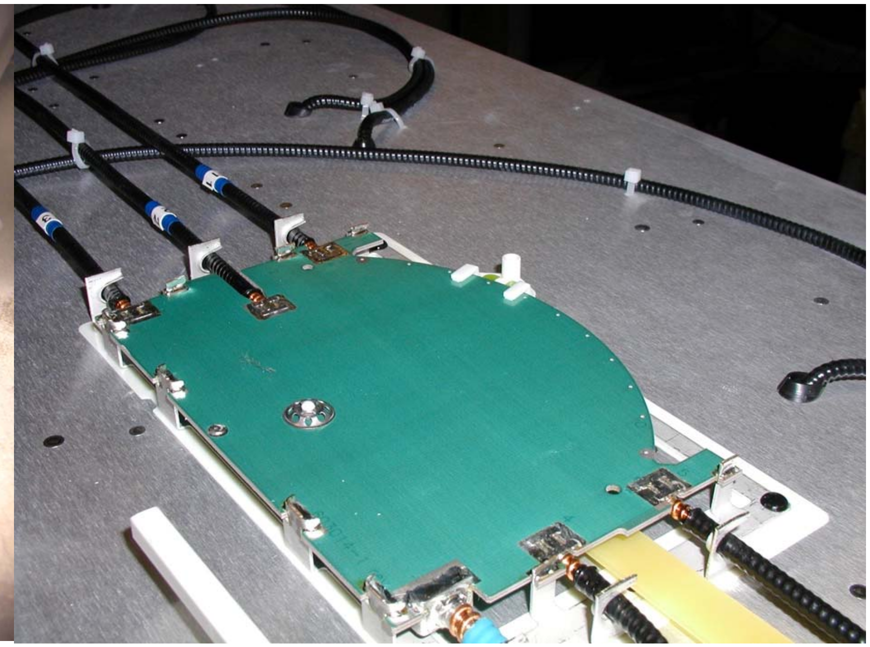
- Dielectric substrate
  - Uses *printed circuit* technology
  - Power limitations
  - Dielectric substrate causes loss (~1.0 dB/m at 2 GHz)
- Air substrate
  - Metal strip spaced above a groundplane
  - Minimal solder or welded joints
  - Laser cut or punched
  - Air substrate cause minimal loss (~0.1 dB/m at 2 GHz)

Air Microstrip Network

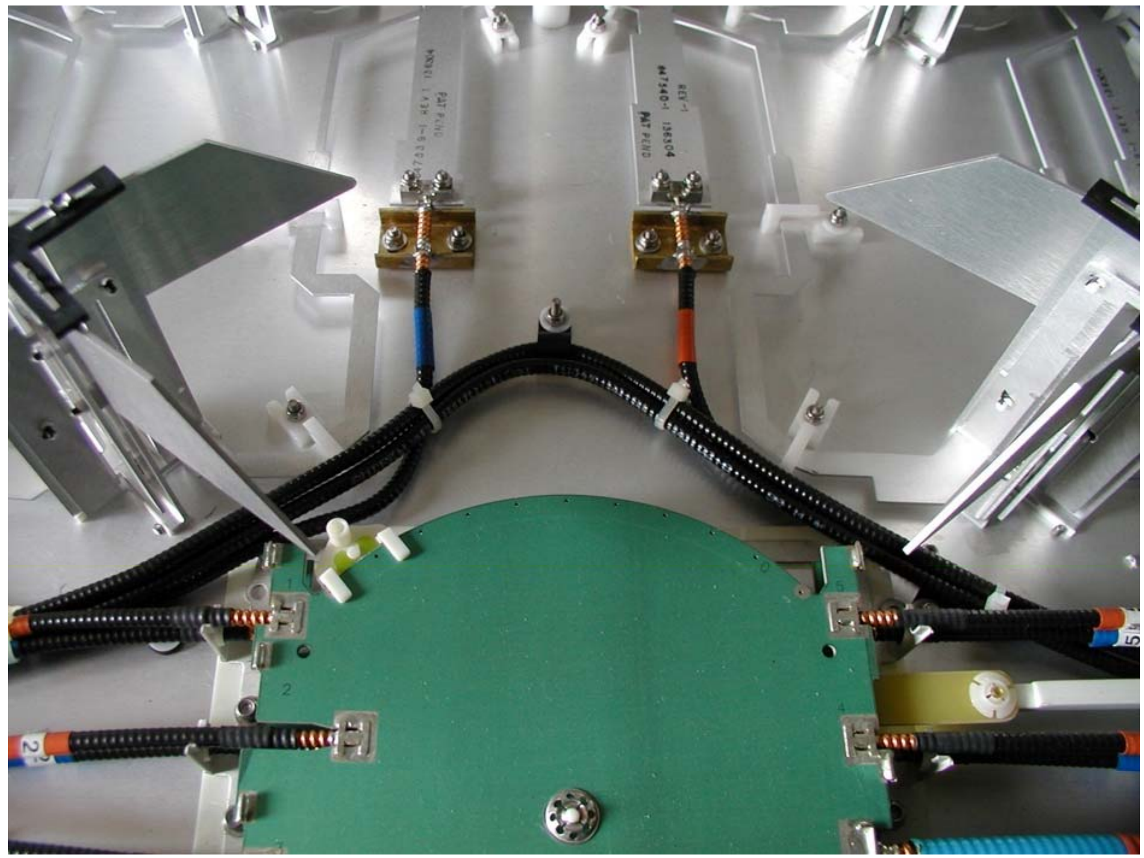
LBX-3316-VTM

Using Hybrid Cable/Air Stripline



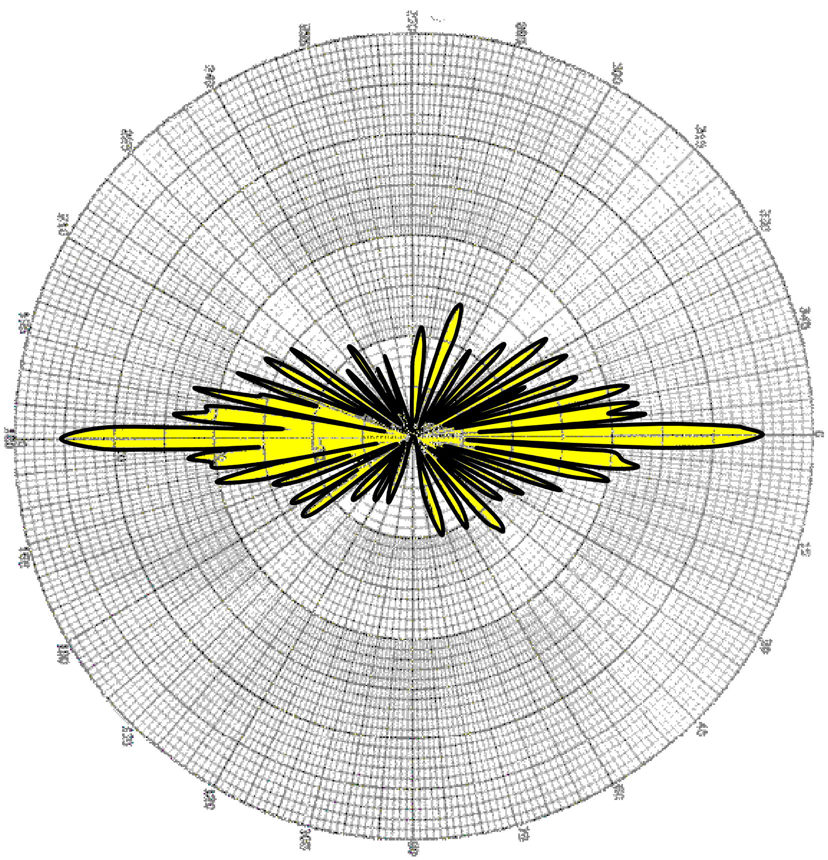


LBX-3319-VTM
Using Hybrid Cable/Air Stripline



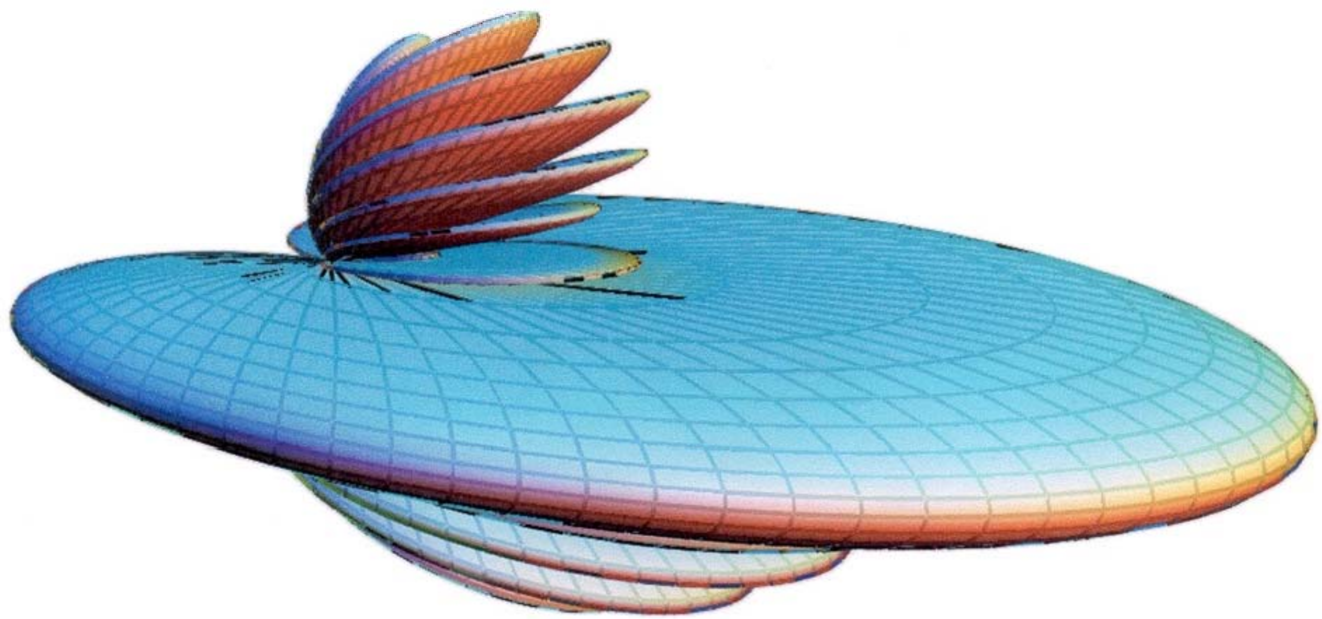
DB812 Omni Antenna

Vertical Pattern



932DG65T2E-M

Pattern Simulation



Key Antenna Pattern Objectives

For sector antenna, the key pattern objective is to focus as much energy as possible into a desired sector with a desired radius while minimizing unwanted interference to/from all other sectors.

This requires:

- Optimized pattern shaping
- Pattern consistency over the rated frequency band
- Pattern consistency for polarization diversity models
- Downtilt consistency

Main Lobe

What is it?

The main lobe is the radiation pattern lobe that contains the majority portion of radiated energy.

Why is it useful?

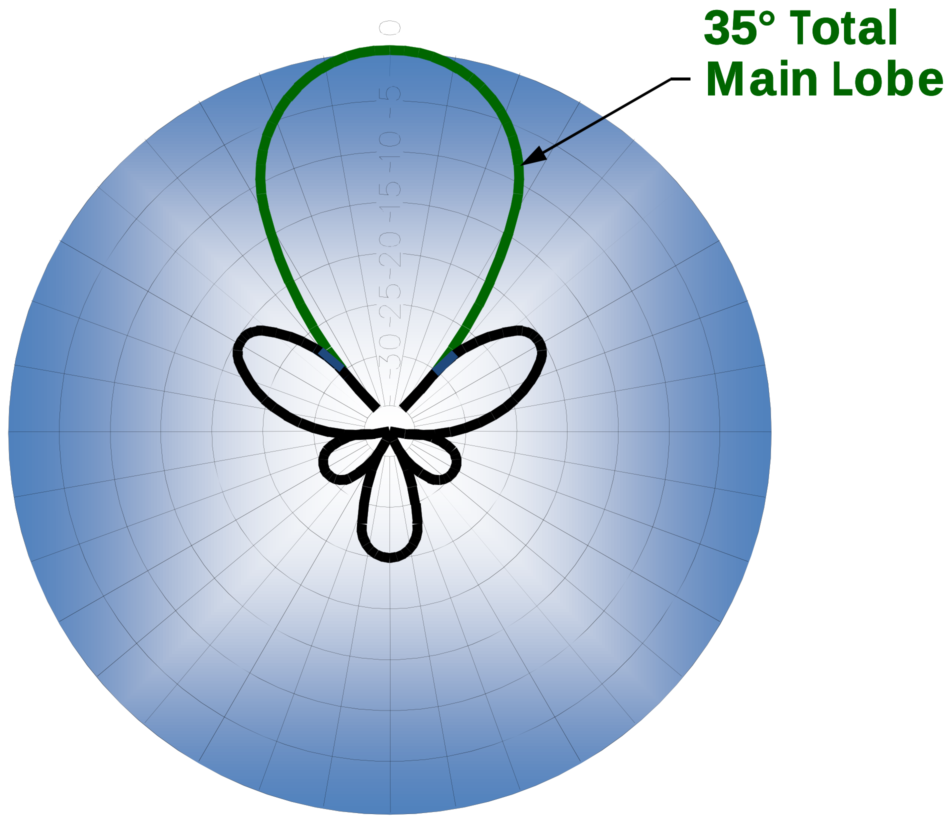
Shaping of the pattern allows the contained coverage necessary for interference-limited system designs.

How is it measured?

The main lobe is characterized using a number of the measurements which will follow.

What is Andrew standard?

Andrew conforms to the industry standard.



Half-Power Beamwidth

Horizontal And Vertical

What is it?

The angular span between the half-power (-3 dB) points measured on the cut of the antenna's main lobe radiation pattern.

Why is it useful?

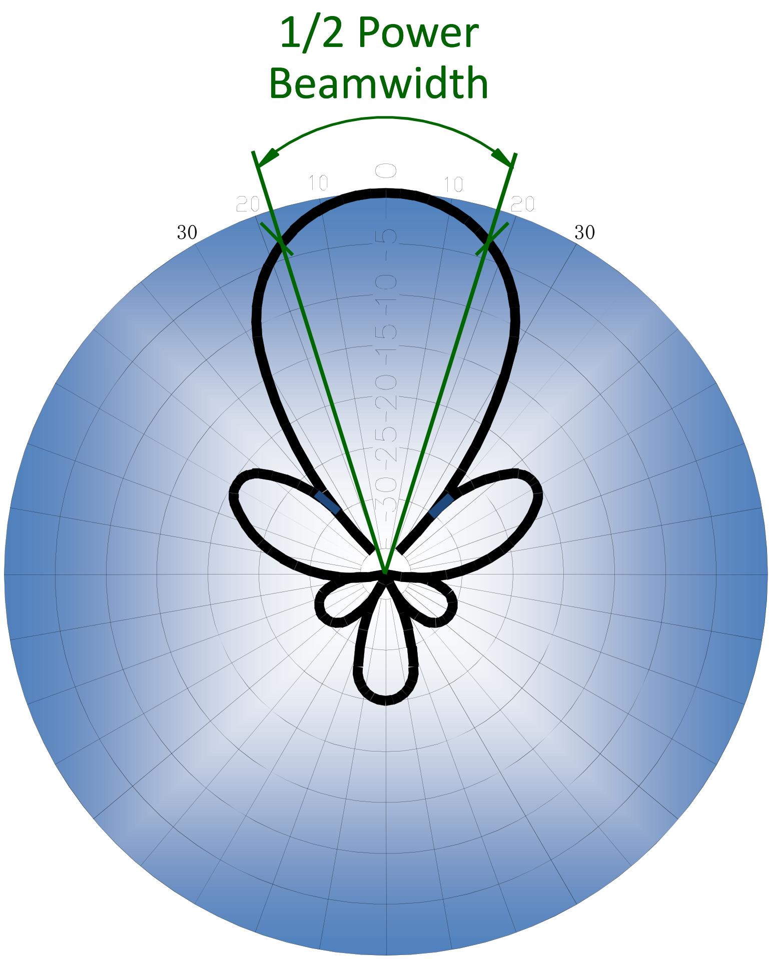
It allows system designers to choose the optimum characteristics for coverage vs. interference requirements.

How is it measured?

It is measured using data collected from antenna range testing.

What is Andrew standard?

Andrew conforms to the industry standard.



Front-To-Back Ratio

What is it?

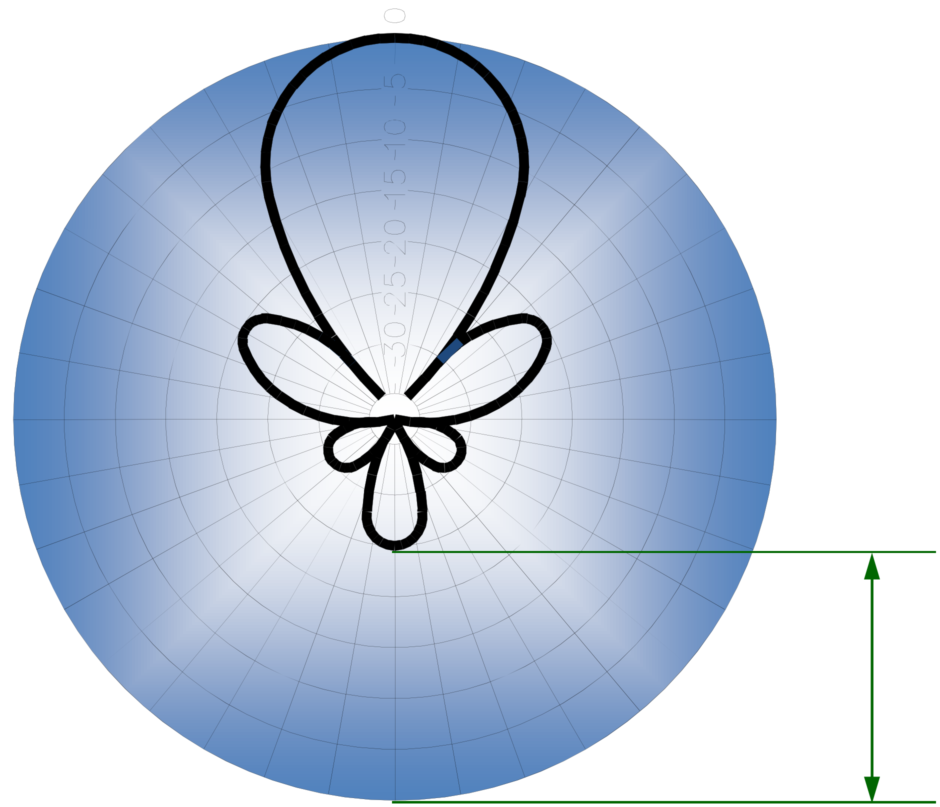
The ratio in dB of the maximum directivity of an antenna to its directivity in a specified rearward direction. Note that on a dual-polarized antenna, it is the sum of co-pol and cross-pol patterns.

Why is it useful?

It characterizes unwanted interference on the backside of the main lobe. The larger the number, the better!

How is it measured?

It is measured using data collected from antenna range testing.



F/B Ratio @ 180 degrees
0 dB – 25 dB = 25 dB

What is Andrew standard?

Each data sheet shows specific performance. In general, traditional dipole and patch elements will yield 23–28 dB while the Directed Dipole™ style elements will yield 35–40 dB.

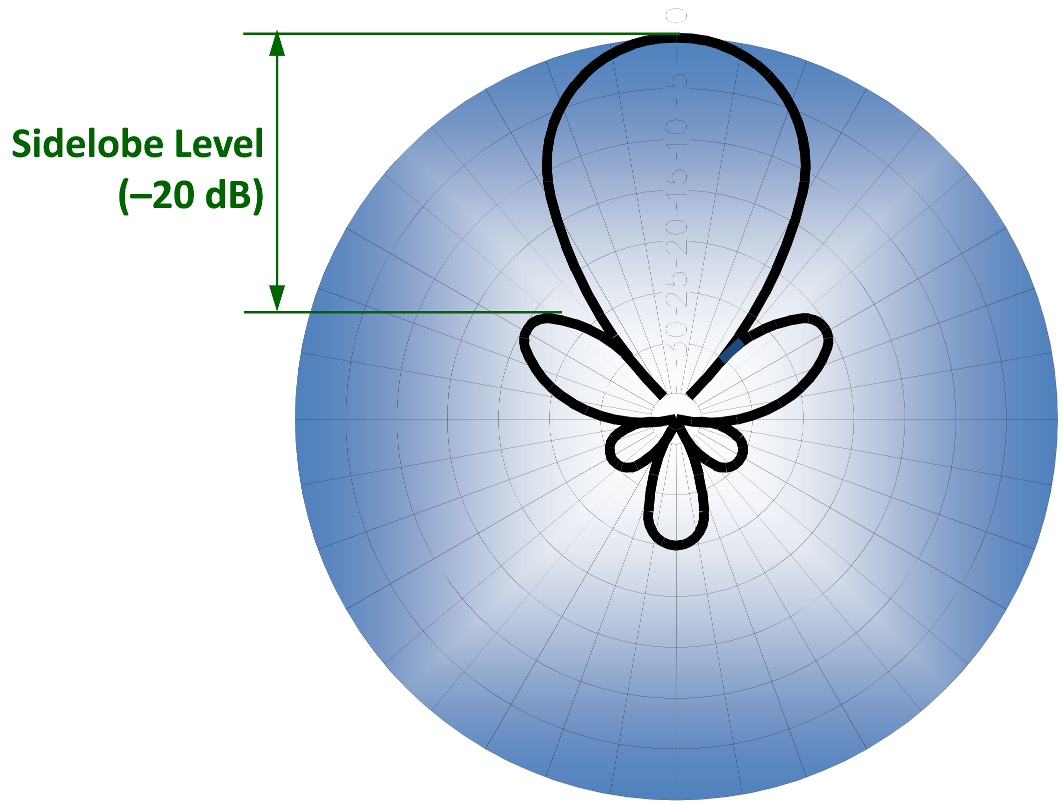
Sidelobe Level

What is it?

Sidelobe level is a measure of a particular sidelobe or angular group of sidelobes with respect to the main lobe.

Why is it useful?

Sidelobe level or pattern shaping allows the minor lobe energy to be tailored to the antenna's intended use. See Null Fill and Upper Sidelobe Suppression.



How is it measured?

It is always measured with respect to the main lobe in dB.

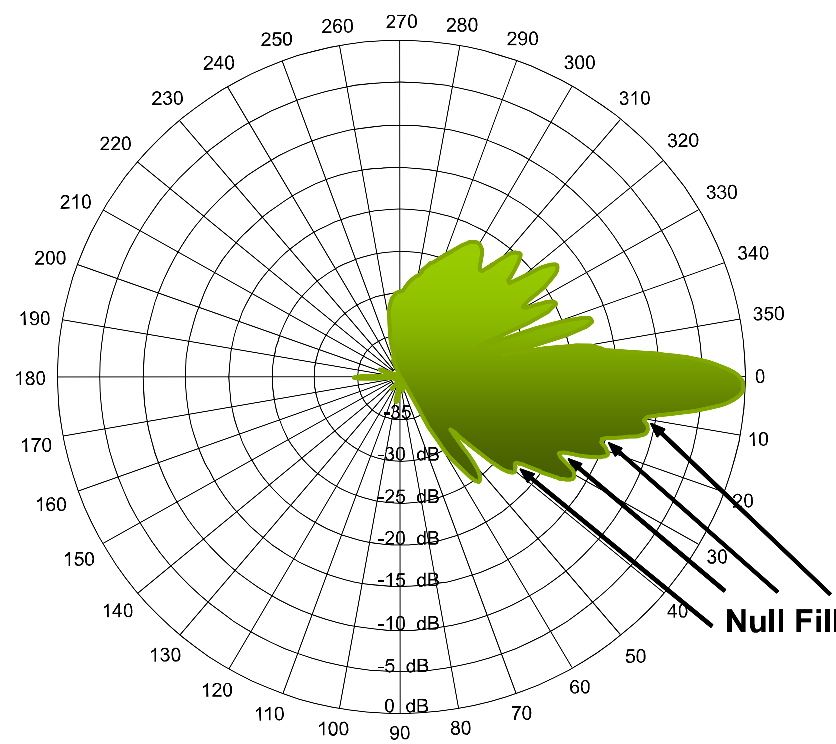
What is Andrew standard?

Andrew conforms to the industry standard.

Null Filling

What is it?

Null filling is an array optimization technique that reduces the null between the lower lobes in the elevation plane.



Why is it useful?

For arrays with a narrow vertical beam-width (less than 12°), null filling significantly improves signal intensity in all coverage targets below the horizon.

How is it measured?

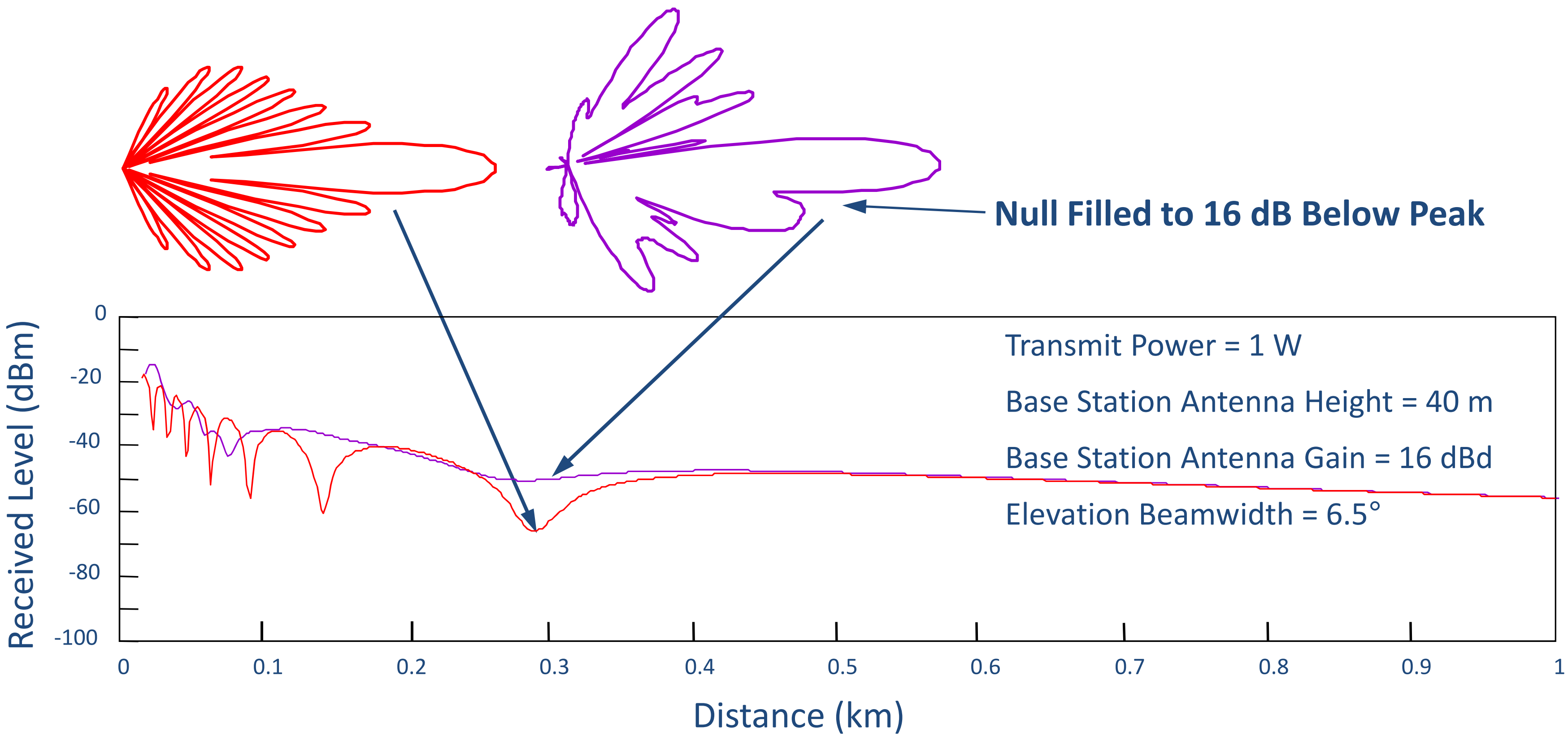
Null fill is easiest explained as the relative dB difference between the peak of the main beam and the depth of the 1st lower null.

What is Andrew standard?

Most Andrew arrays will have null fill of 20–30 dB without optimization. To qualify as null fill, we expect no less than 15 and typically 10–12 dB!

Null Filling

Important For Antennas With Narrow Elevation Beamwidths



Upper Sidelobe Suppression

What is it?

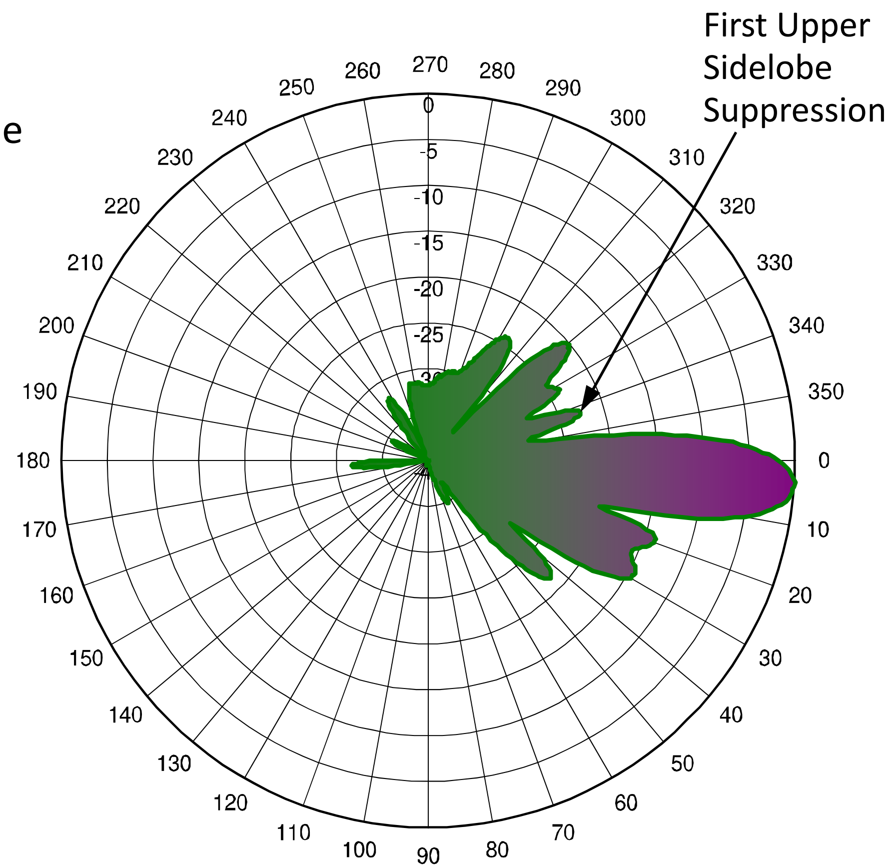
Upper sidelobe suppression (USLS) is an array optimization technique that reduces the undesirable sidelobes above the main lobe.

Why is it useful?

For arrays with a narrow vertical beamwidth (less than 12°), USLS can significantly reduce interference due to multi-path or when the antenna is mechanically downtilted.

How is it measured?

USLS is the relative dB difference between the peak of the main beam peak of the first upper sidelobe.



What is Andrew standard?

Most of Andrew's arrays will have USLS of >15 dB without optimization. The goal of all new designs is to suppress the first upper sidelobe to unity gain or lower.

Orthogonality

What is it?

The ability of an antenna to discriminate between two waves whose polarization difference is 90 degrees.

Why is it useful?

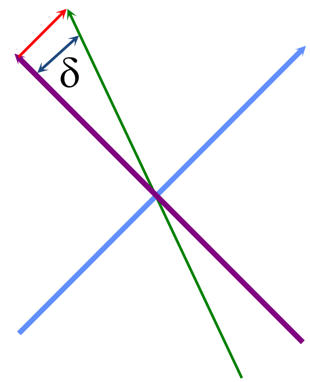
Orthogonal arrays within a single antenna allow for polarization diversity. (As opposed to spacial diversity.)

How is it measured?

The difference between the co-polar pattern and the cross-polar pattern, usually measured in the boresite
(the direction of the main signal).

What is Andrew standard?

Andrew conforms to the industry standard.



Decorrelation between the Green and Blue Lines

δ = 0°, XPol = –∞ dB
δ = 5°, XPol = –21 dB
δ = 10°, XPol = –15 dB
δ = 15°, XPol = –11 dB
δ = 20°, XPol = –9 dB
δ = 45°, XPol = –3 dB
δ = 50°, XPol = –2.3 dB
δ = 60°, XPol = –1.2 dB
δ =70°, XPol = –0.54 dB
δ =80°, XPol = –0.13 dB
δ =90°, XPol = 0 dB

XPol = 20 log (sin (δ))

Cross-Pol Ratio (CPR)

What is it?

CPR is a comparison of the co-pol vs. cross-pol pattern performance of a dual-polarized antenna generally over the sector of interest (alternatively over the 3 dB beamwidth).

Why is it useful?

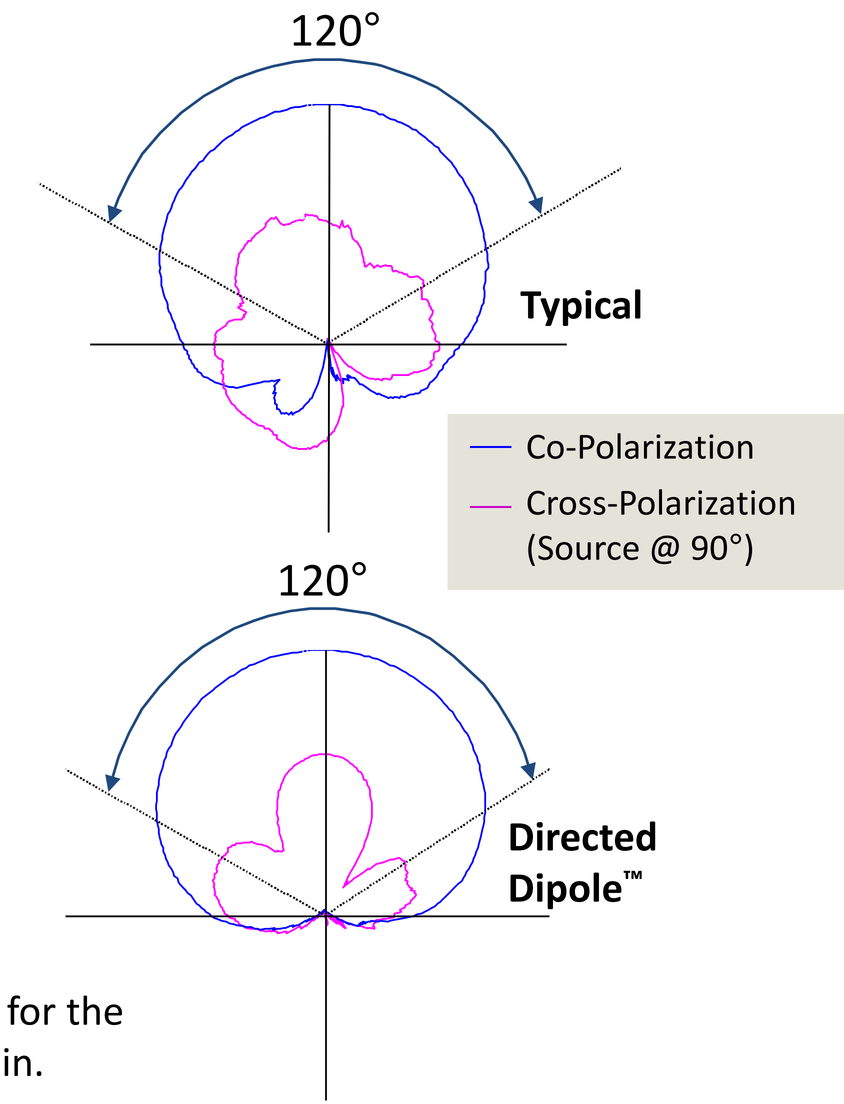
It is a measure of the ability of a cross-pol array to distinguish between orthogonal waves. The better the CPR, the better the performance of polarization diversity.

How is it measured?

It is measured using data collected from antenna range testing and compares the two plots in dB over the specified angular range. Note: in the rear hemisphere, cross-pol becomes co-pol and vice versa.

What is Andrew standard?

For traditional dipoles, the minimum is 10 dB; however, for the Directed Dipole™ style elements, it increases to 15 dB min.



Horizontal Beam Tracking

What is it?

It refers to the beam tracking between the two beams of a +/–45° polarization diversity antenna over a specified angular range.

Why is it useful?

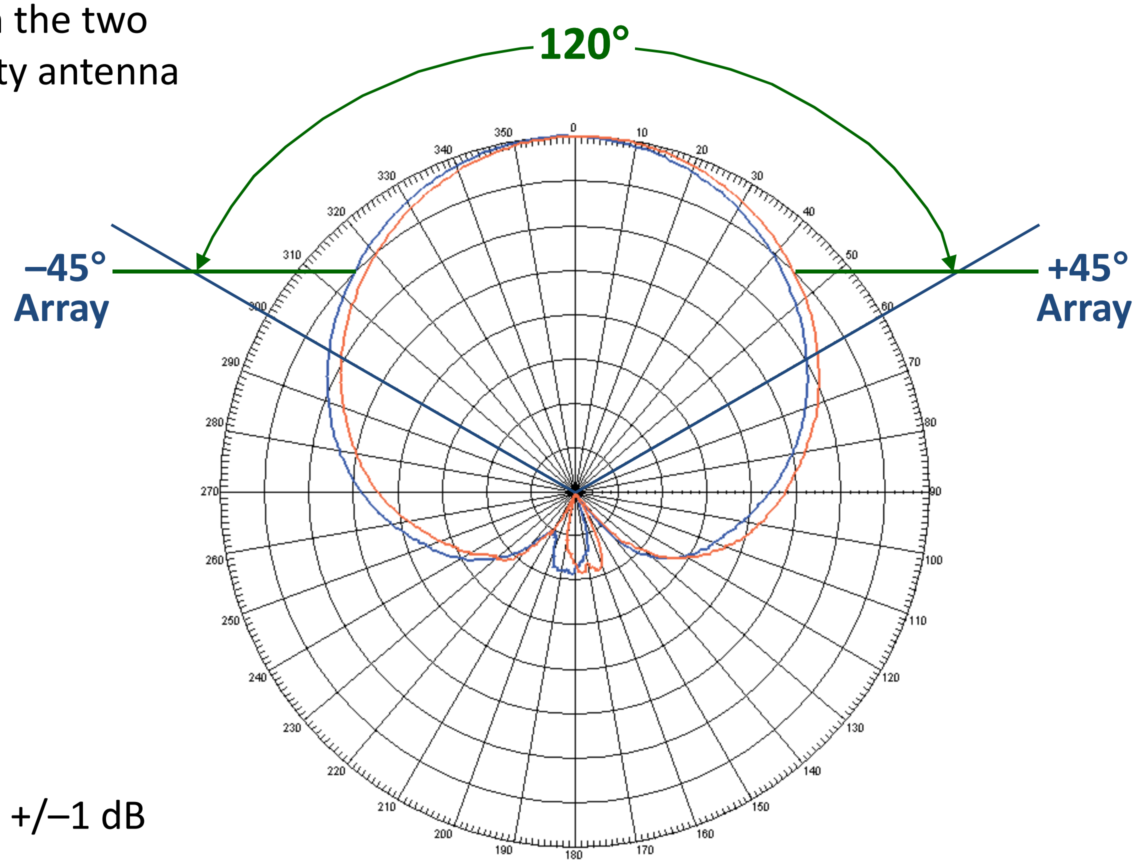
For optimum diversity performance, the beams should track as closely as possible.

How is it measured?

It is measured using data collected from antenna range testing and compares the two plots in dB over the specified angular range.

What is Andrew standard?

The Andrew beam tracking standard is +/–1 dB over the 3 dB horizontal beamwidth.



Beam Squint

What is it?

The amount of pointing error of a given beam referenced to mechanical boresite.

Why is it useful?

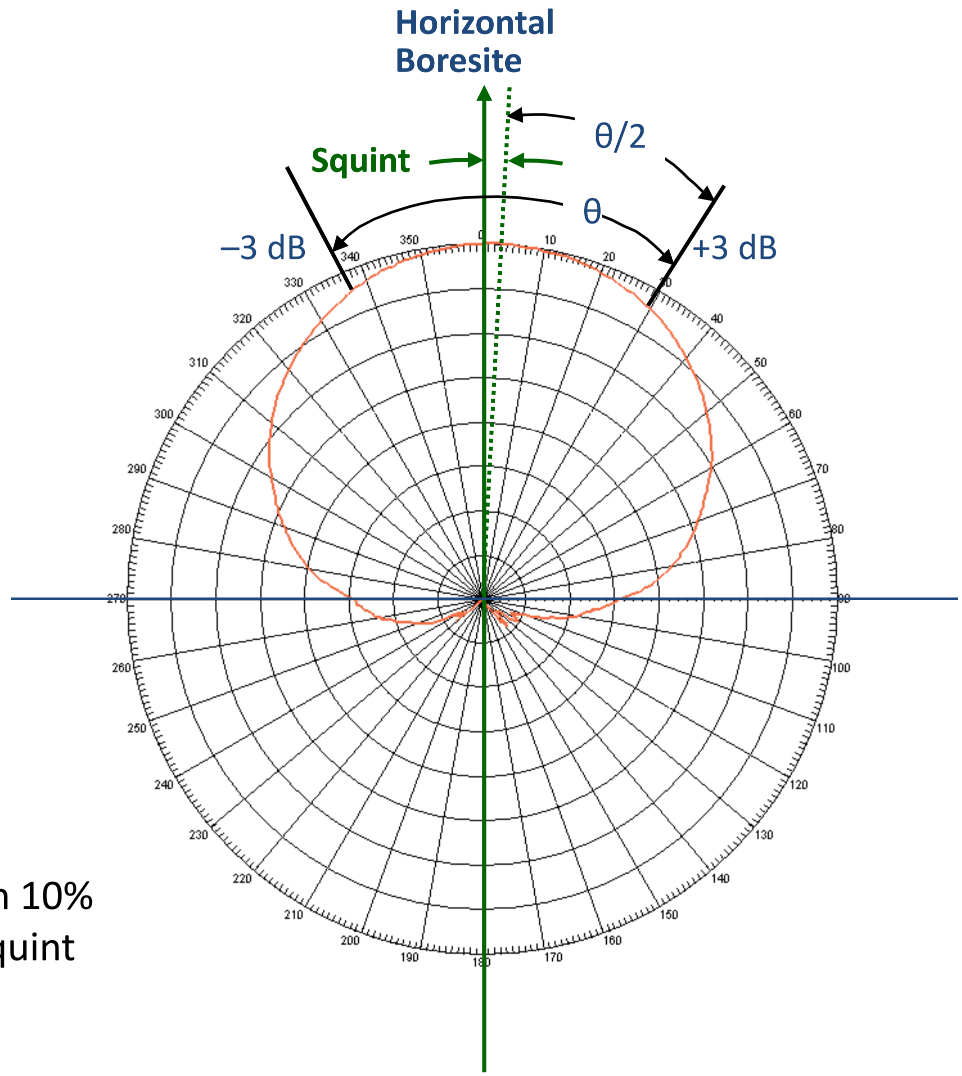
The beam squint can affect the sector coverage if it is not at mechanical boresite. It can also affect the performance of the polarization diversity style antennas if the two arrays do not have similar patterns.

How is it measured?

It is measured using data collected from antenna range testing.

What is Andrew standard?

For the horizontal beam, squint shall be less than 10% of the 3 dB beamwidth. For the vertical beam, squint shall be less than 15% of the 3 dB beamwidth or 1 degree, whichever is greatest.



Sector Power Ratio (SPR)

What is it?

SPR is a ratio expressed in percentage of the power outside the desired sector to the power inside the desired sector created by an antenna's pattern.

Why is it useful?

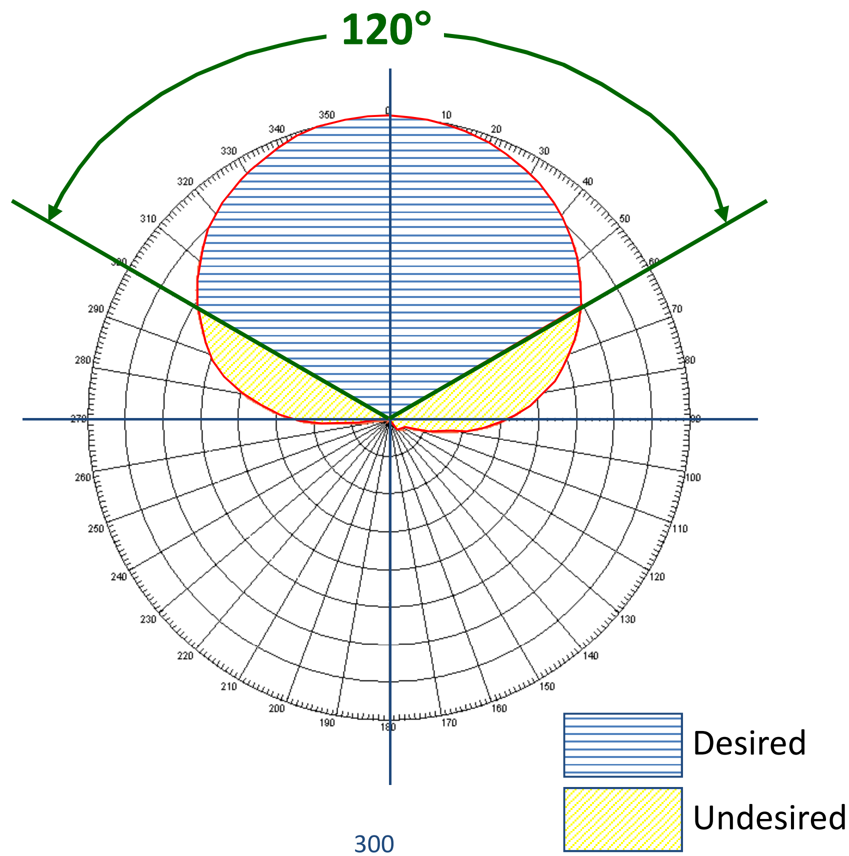
It is a percentage that allows comparison of various antennas. The better the SPR, the better the interference performance of the system.

How is it measured?

It is mathematically derived from the measured range data.

What is Andrew standard?

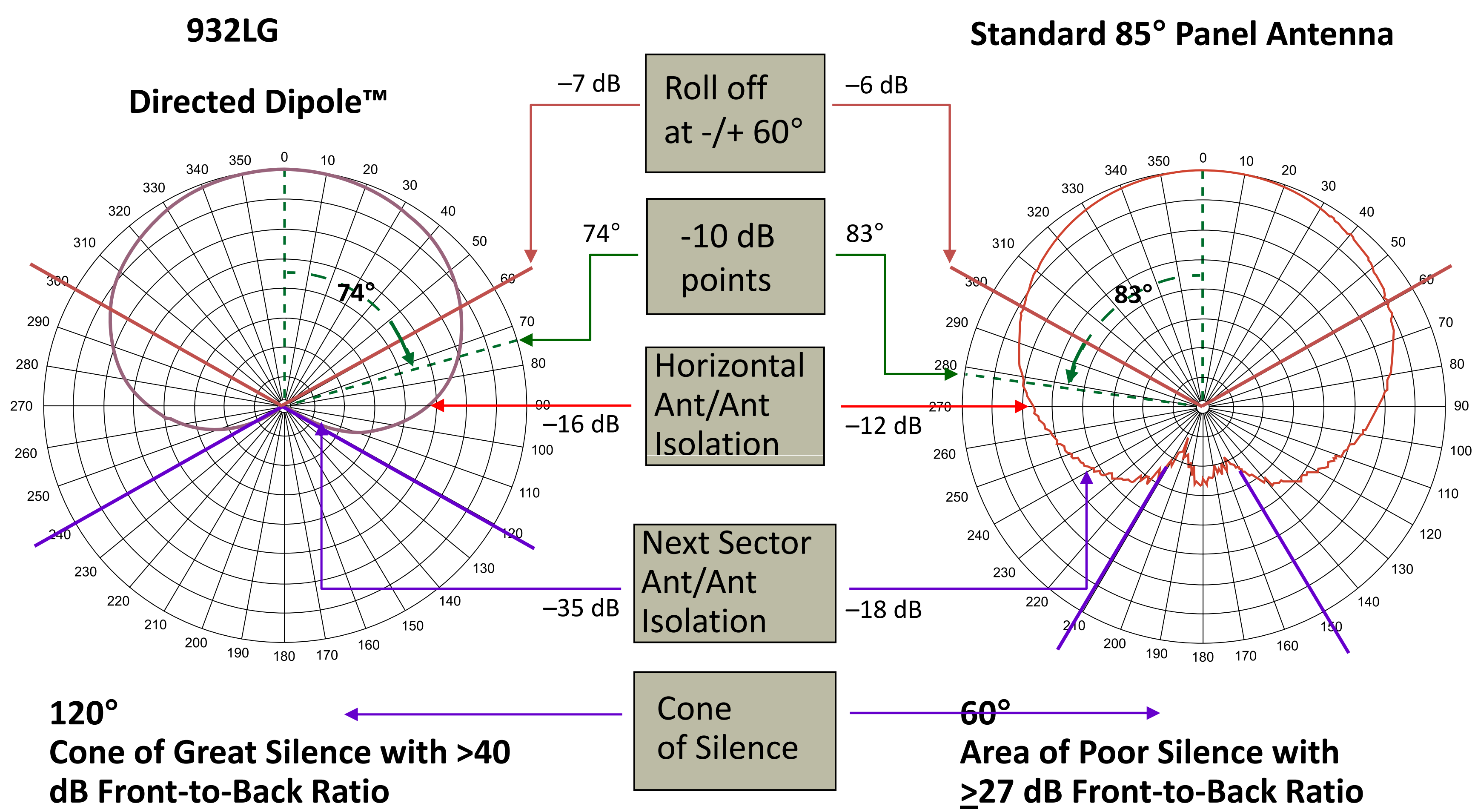
Andrew Directed Dipole™ style antennas have SPR's typically less than 2 percent.



$$SPR\ (\%) = \frac{\sum_{60}^{300} P_{Undesired}}{\sum_{300}^{60} P_{Desired}} \times 100$$

Antenna–Based System Improvements

Key Antenna Parameters To Examine Closely



Key Antenna Pattern Objectives

	Urban	Suburban	Rural
Azimuth Beam			
• Beam tracking vs. frequency Limited to sub-bands on broadband models	1	1	1
• Squint	1	1	1
• Roll-off past the 3 dB points	1	2	3
• Front-to-back ratio	1	1	2
• Cross-pol beam tracking	1	1	1
Elevation Beam			
• Beam tracking vs. frequency	1	2	3
• Upper sidelobe suppression	1	2	3
• Lower null fill	3	3	2
• Cross-pol beam tracking	2	2	3

Ratings:

1 = Always important

2 = Sometimes important

3 = Seldom important

Key Antenna Pattern Objectives (Continued)

Downtilt

- Electrical vs. mechanical tilt
- Absolute tilt
- Electrical tilt vs. frequency
- Effective gain on the horizon

Gain

- Close to the theoretical value
  (directivity minus losses)

Note: Pattern shaping reduces gain.

	Urban	Suburban	Rural
Electrical vs. mechanical tilt	1	1	3
Absolute tilt	2	2	3
Electrical tilt vs. frequency	1	2	3
Effective gain on the horizon	1	2	3
Close to the theoretical value	2	1	1

Ratings:

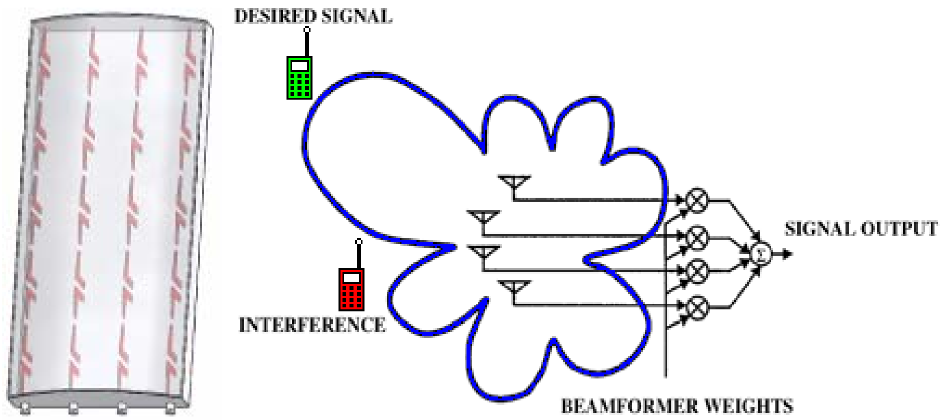
1 = Always important

2 = Sometimes important

3 = Seldom important

Advanced Antenna Technology

Adaptive Array (AA)



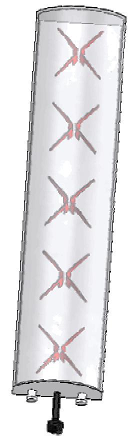
- Planar array
- External digital signal processing (DSP) controls the antenna pattern
- A unique beam tracks each mobile
- Adaptive nulling of interfering signals
- Increased signal to interference ratio performance benefits

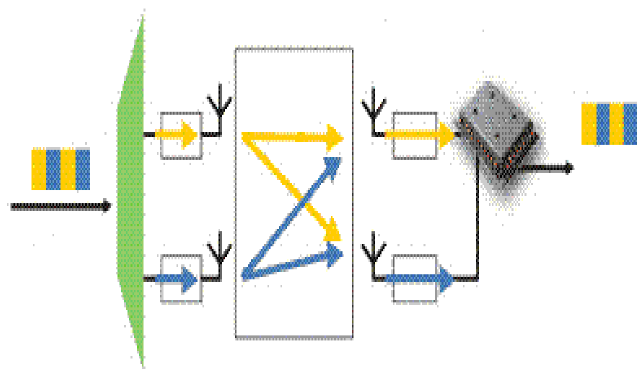
- 4, 6, and 8 column vertical pol designs for WiMAX and TD-SCDMA*
- Often calibration ports are used

* Time Division Spatial Code Division Multiple Access

Advanced Antenna Technology

MIMO Systems





2 x 2 MIMO Spatial Multiplexing

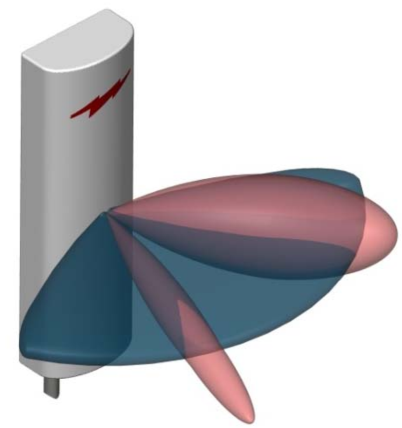
- Multiple Input Multiple Output (MIMO)
- External DSP extracts signal from interference
- Capacity gains due to multiple antennas

- A DualPol® RET for 2x2 MIMO, two separated for 4x4 MIMO
- Spatial multiplexing works best in a multi-path environment
- Space Time Block Coding is a diversity MIMO mode

Advanced Antenna Technology

SmartBeam® Antenna Family

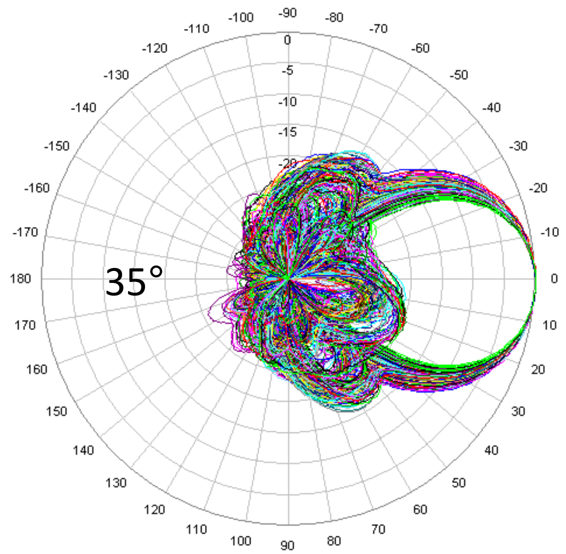
- Most flexible and efficient antenna system in the industry
- Solution for the traffic peaks instead of raising the bar everywhere
- Full 3-way remote optimization options
  - **RET – Remote Electrical Tilt** (e.g. 0–10°)
  - **RAS – Remote Azimuth Steering** (+/– 30°)
  - **RAB – Remote Azimuth Beamwidth** (from 35° to 105°)
- Redirect and widen the beam based on traffic requirements
- Balance the traffic per area with the capacity per sector
- Best utilization of radio capacity per sector
- Convenient and low-cost optimization from a remote office
- Quick and immediate execution
- Scheduled and executed several times a day (e.g. business and residential plan)

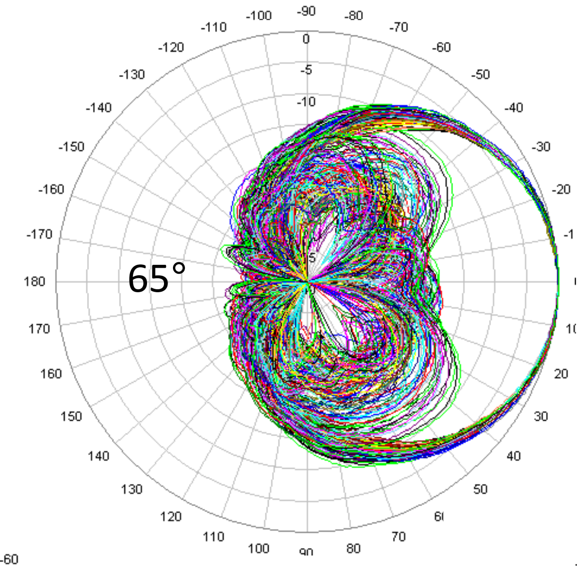


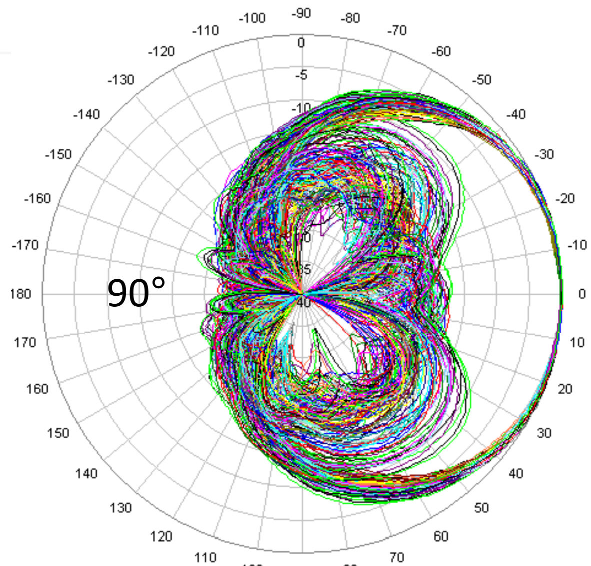
Advanced Antenna Technology

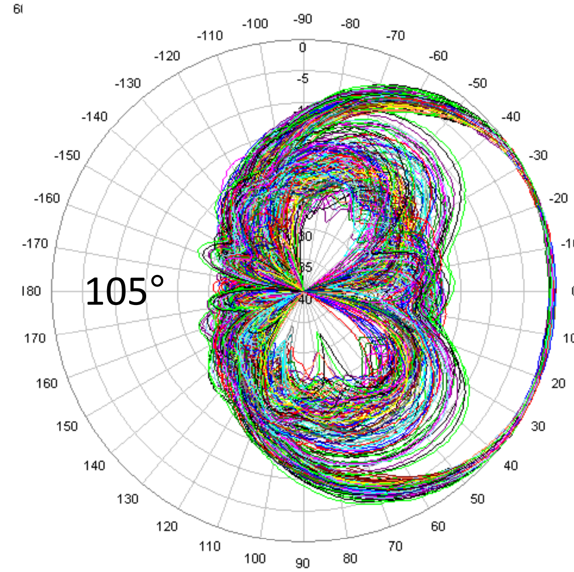
SmartBeam®
3-Way Model

Azimuth patterns measured at 1710–2180 MHz with no radome.

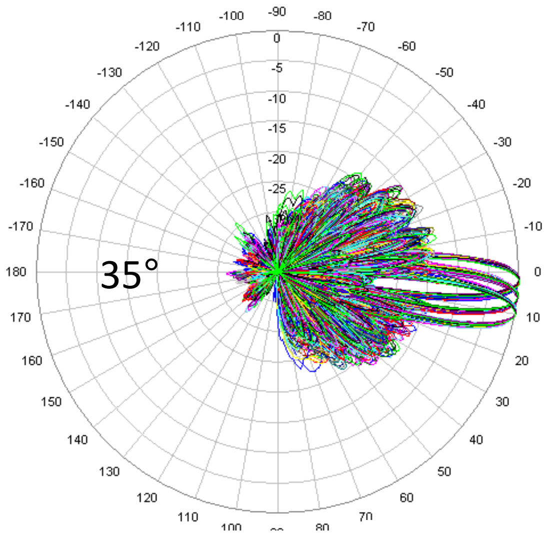


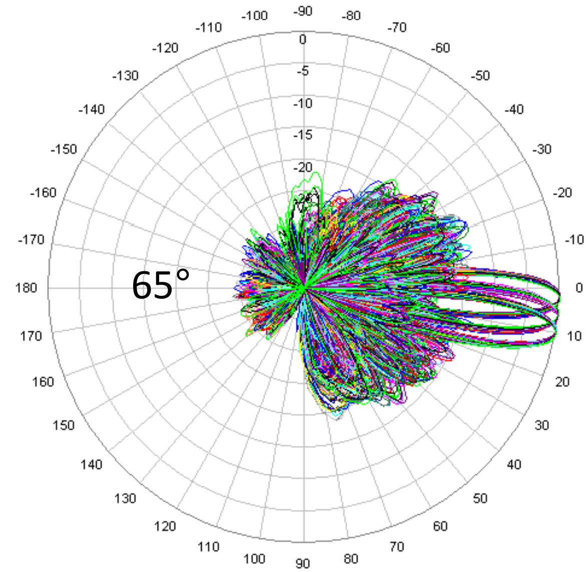






Advanced Antenna Technology

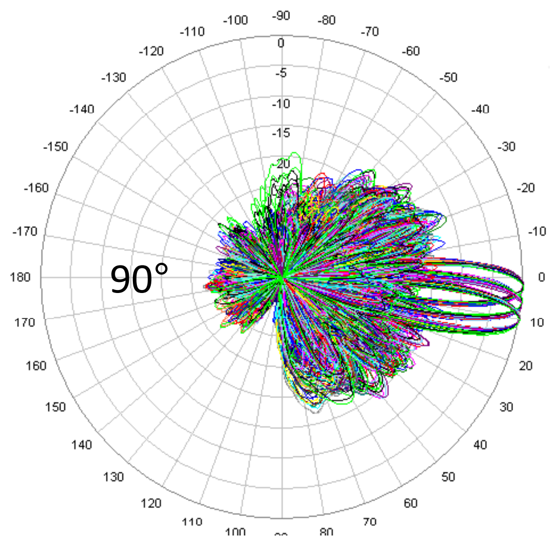


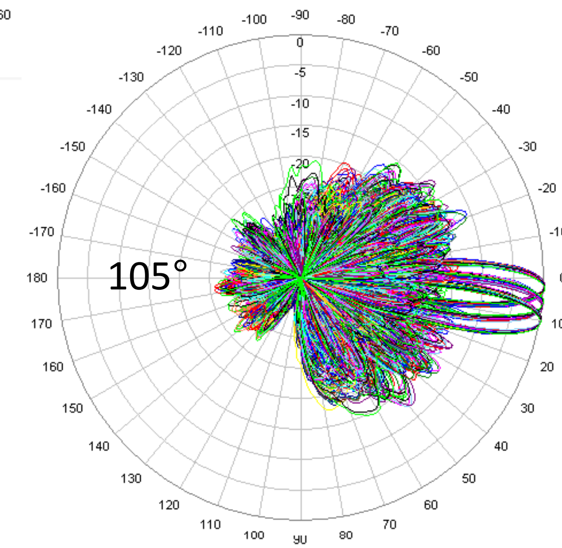


SmartBeam®

3-Way Model

Elevation patterns measured at 1710–2180 MHz with no radome.





System Issues

- Choosing sector antennas
- Narrow beam antenna applications
- Polarization—vertical vs. slant 45°
- Downtilt—electrical vs. mechanical
- RET optimization
- Passive intermodulation (PIM)
- Return loss through coax
- Antenna isolation
- Pattern distortion

Choosing Sector Antennas

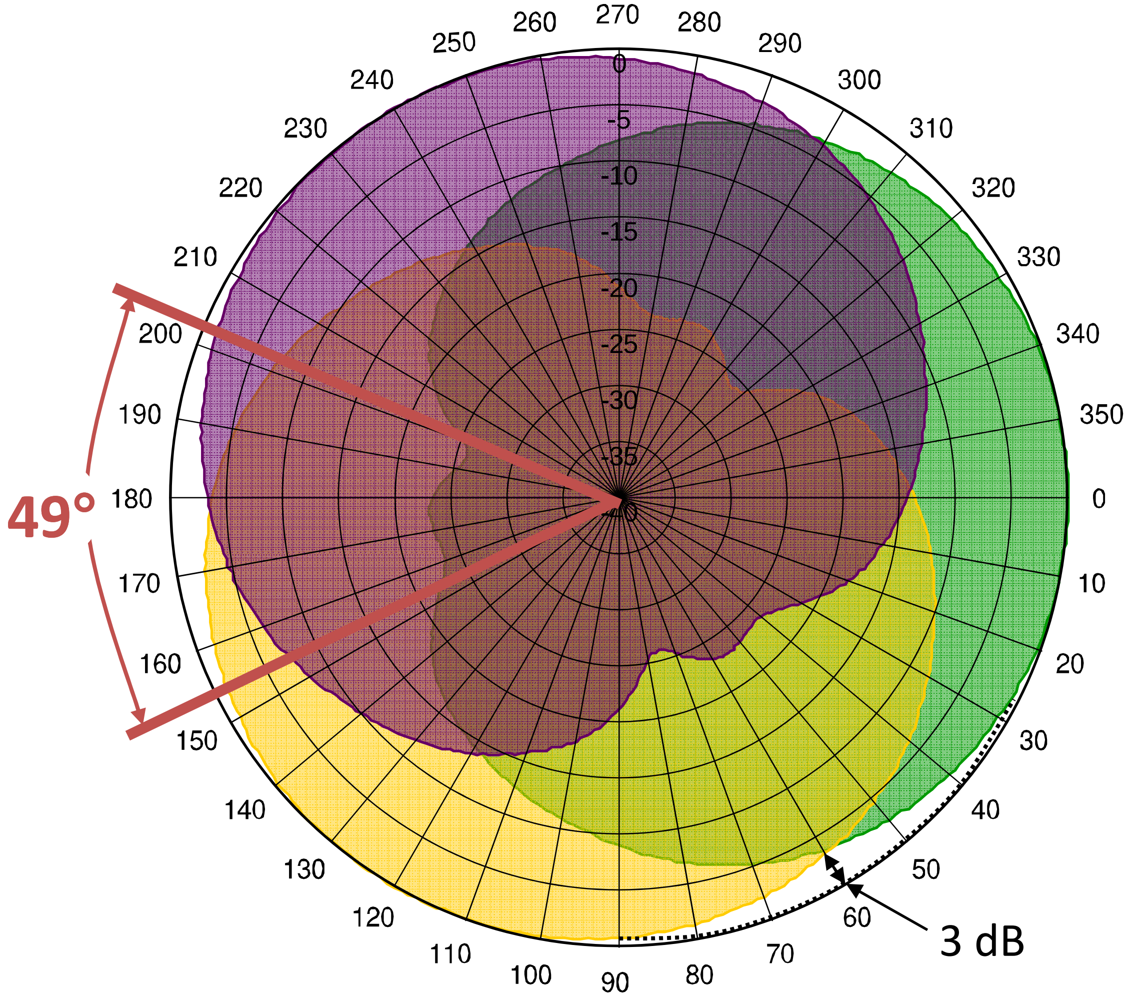
For 3 sector cell sites, what performance differences can be expected from the use of antennas with different horizontal apertures?

Criteria

- Area of service indifference between adjacent sectors (*ping-pong* area)
- For comparison, use 6 dB differentials
- Antenna gain and overall sector coverage comparisons

3 x 120° Antennas

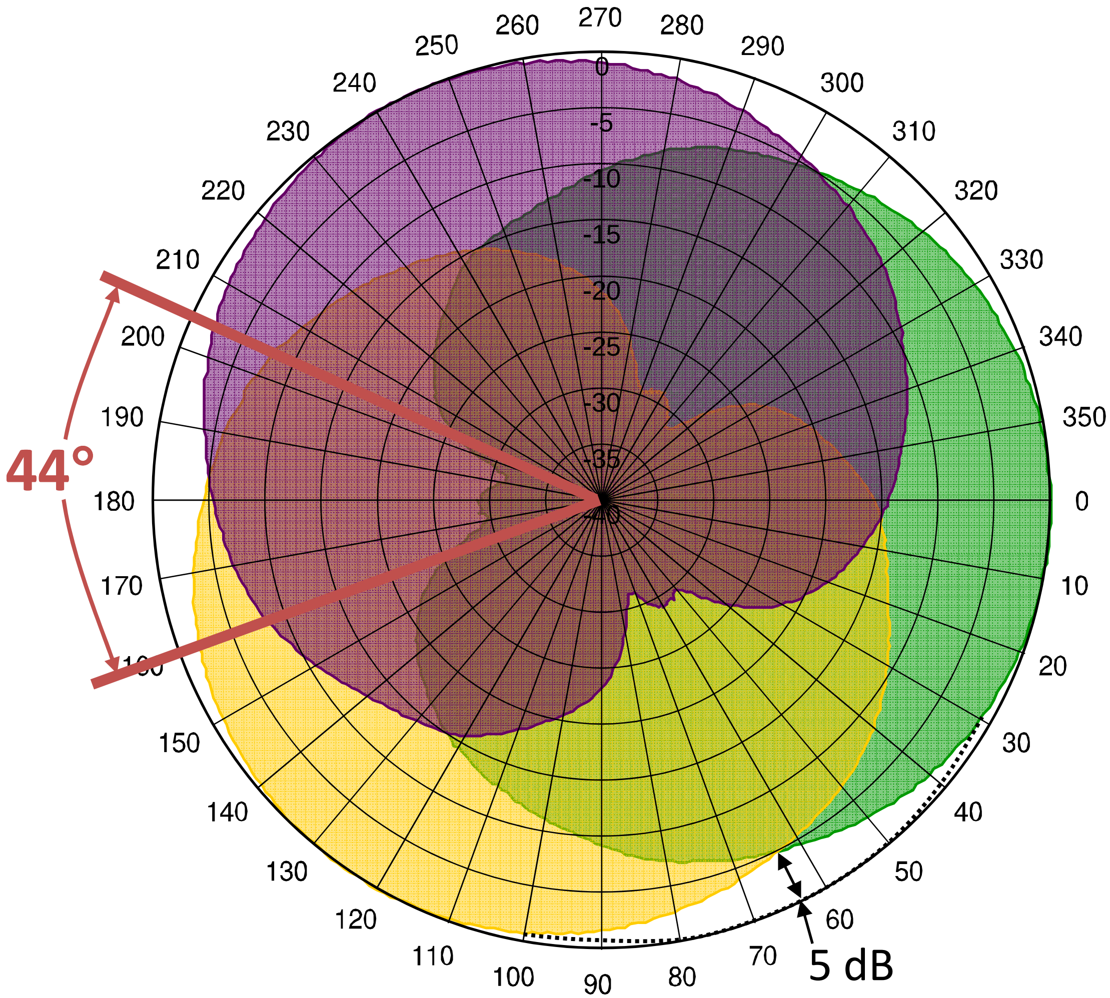
120° Horizontal Overlay Pattern



Examples
VPol
Low Band DB874H120 DB878H120

3 x 90° Antennas

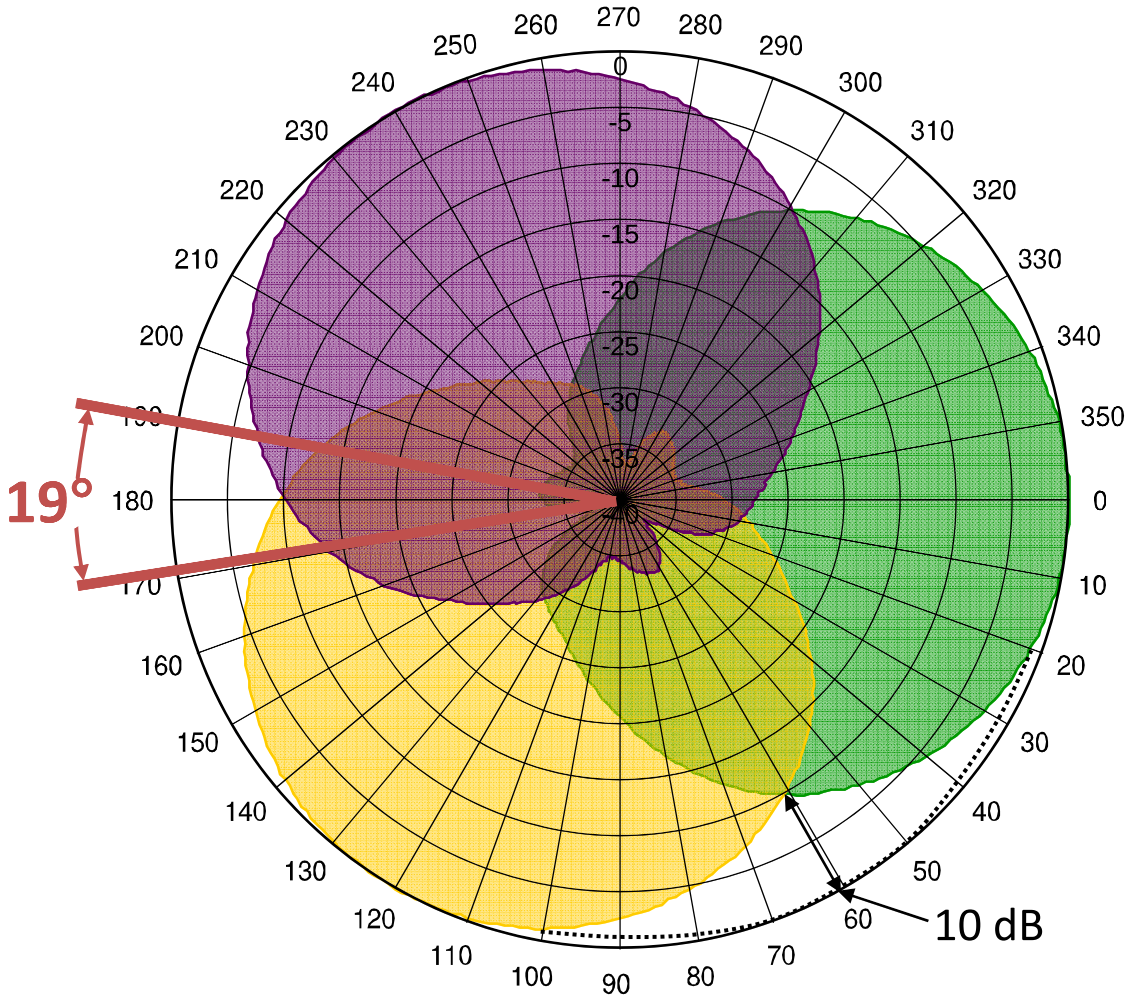
90° Horizontal Overlay Pattern



Examples	
XPol	**VPol**
Low Band	
DB854DG90	DB842H90
DB856DG90	DB844H90
DB858DG90	DB848H90
LBX-9012	LBV-9012
LBX-9013	
High Band	
DB932DG90	UMW-9015
DB950G85	
HBX-9016	
UMWD-09014B	
UMWD-09016	

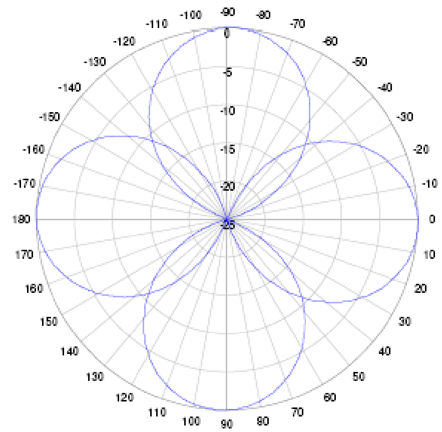
3 x 65° Antennas

65° Horizontal Overlay Pattern

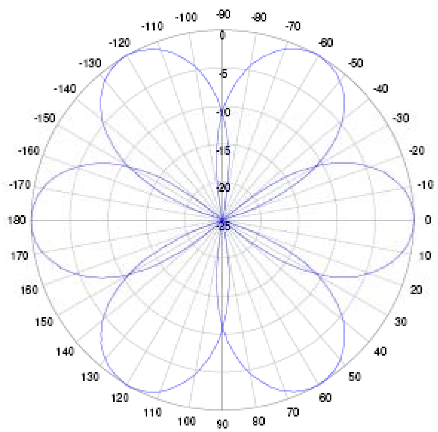


Examples	
XPol	**VPol**
Low Band	
CTSDG-06513	DB844H65
CTSDG-06515	DB848H65
CTSDG-06516	LBV-6513
DB854DG65	
DB856DG65	
DB858DG65	
LBX-6513	
LBX-6516	
High Band	
UMWD-06513	PCS-06509
UMWD-06516	HBV-6516
UMWD-06517	HBV-6517
HBX-6516	
HBX-6517	

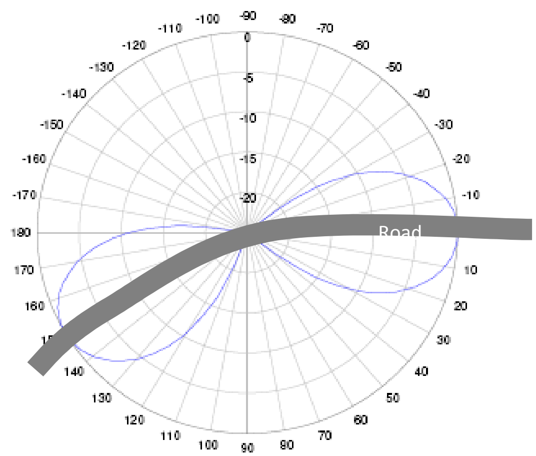
Special Narrow Beam Applications



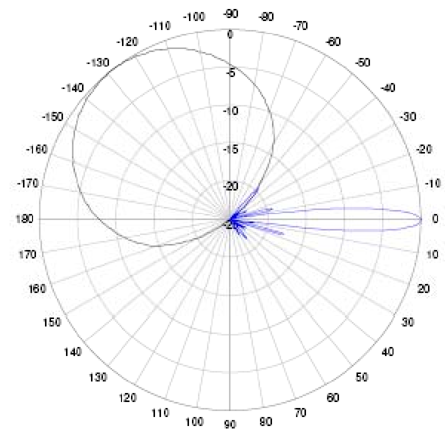
4-Sector Site (45°)



6-Sector Site (33°)



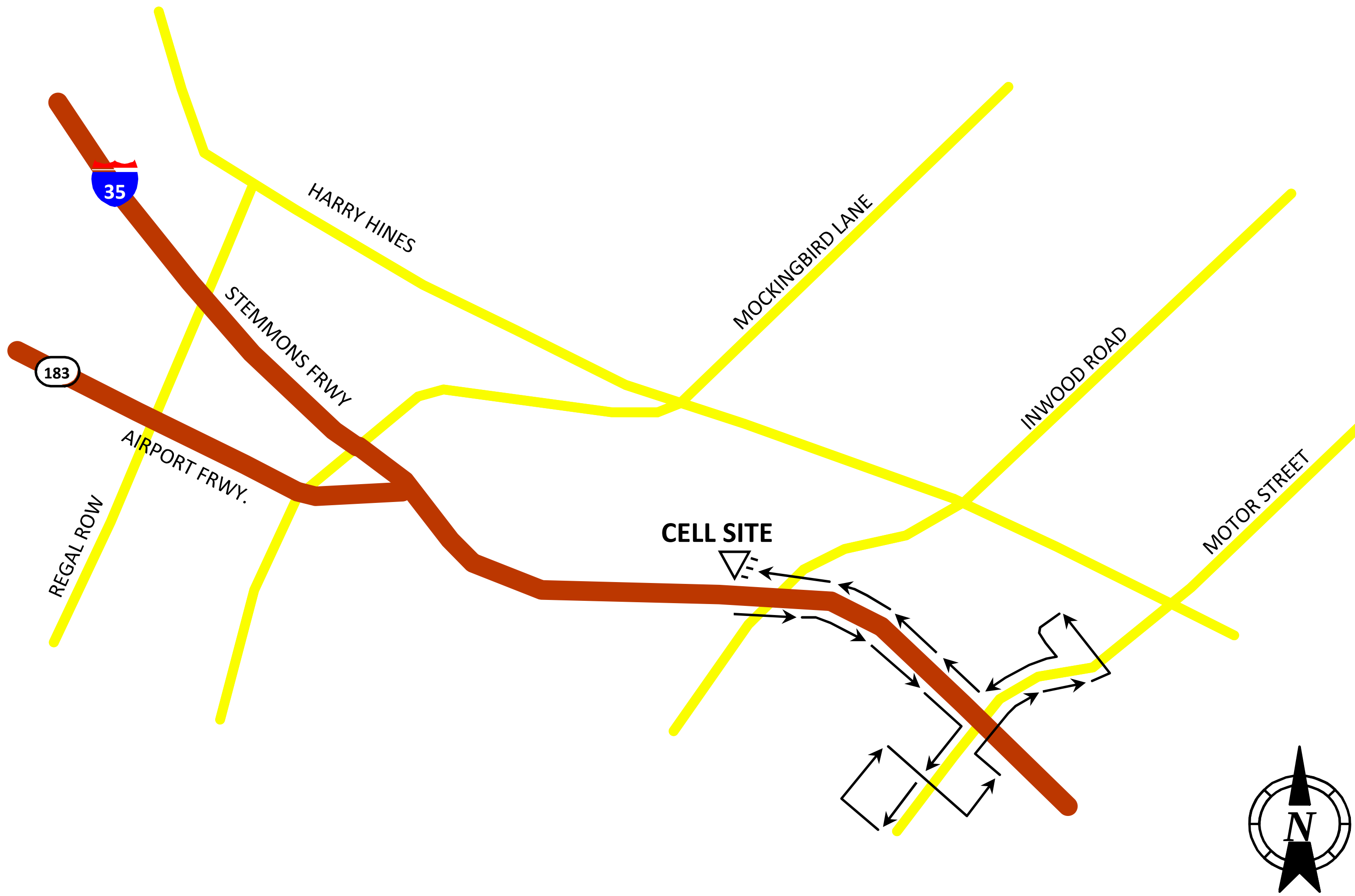
Rural Roadway



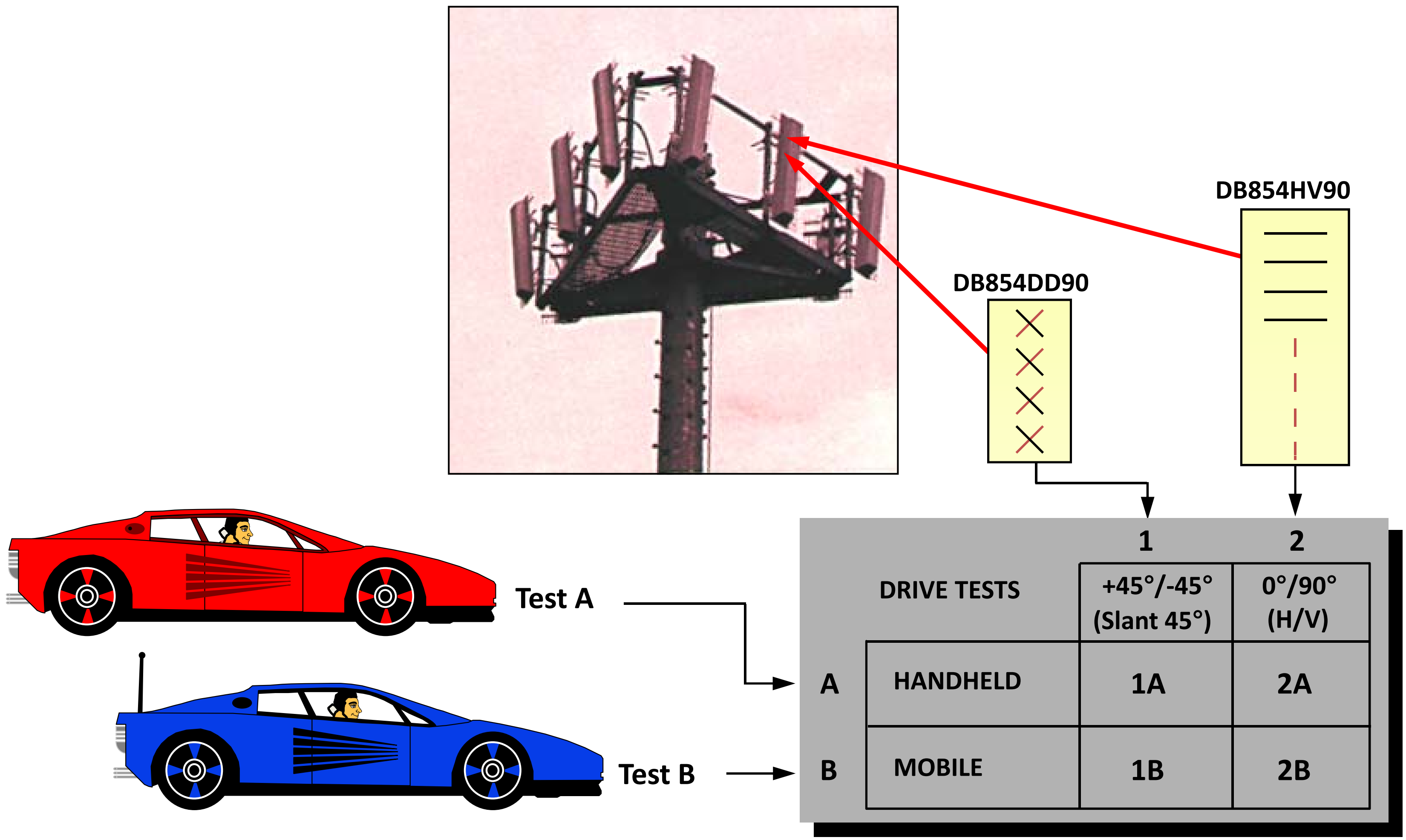
Repeater

Narrow Donor,
Wide Coverage
Antennas

Test Drive Route



Polarization Diversity Tests

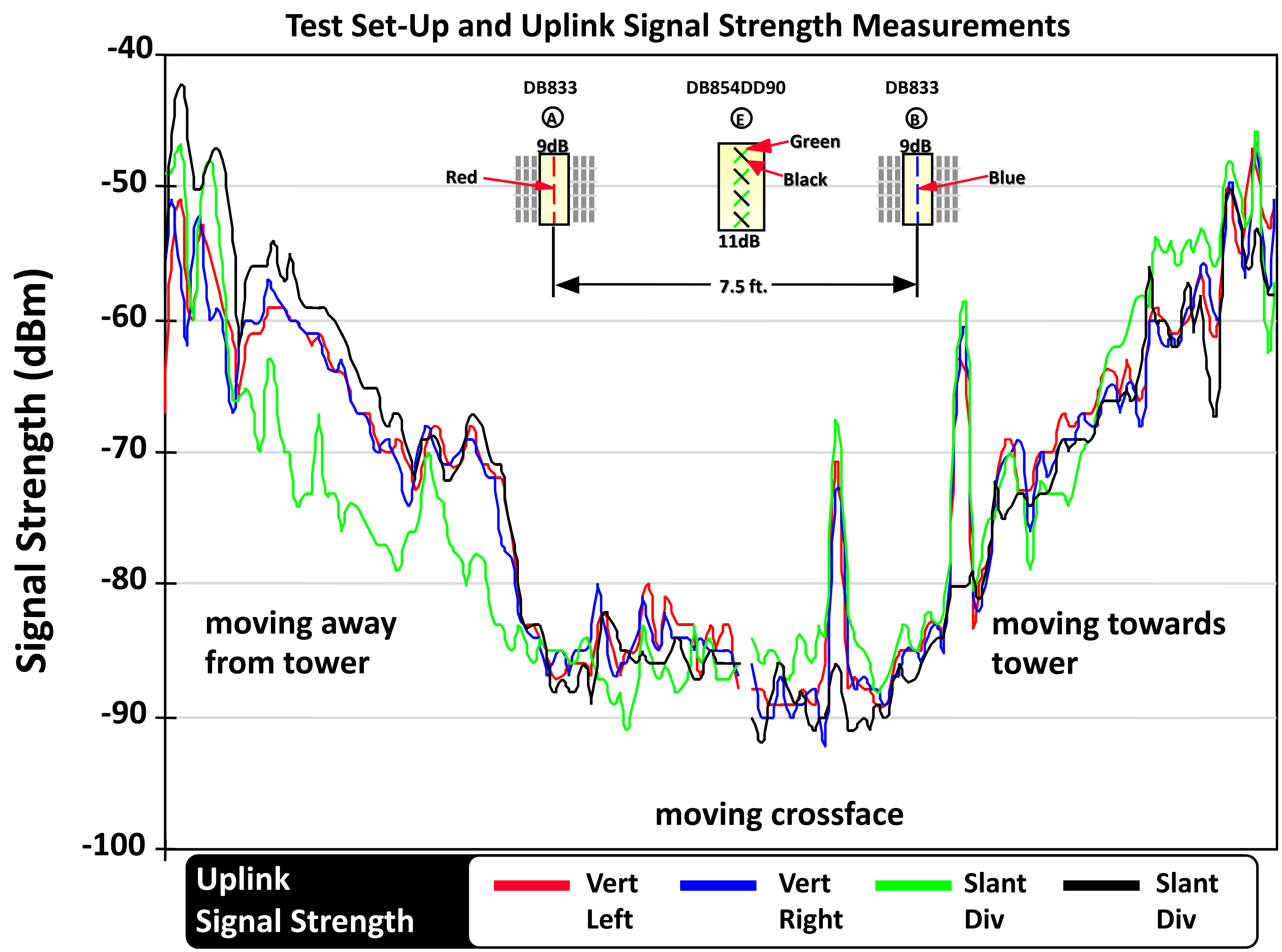


		1	2
	DRIVE TESTS	+45°/-45° (Slant 45°)	0°/90° (H/V)
A	HANDHELD	1A	2A
B	MOBILE	1B	2B

Slant 45° / Hand-Held In Car

Space Diversity vs. Slanted +45°/–45°

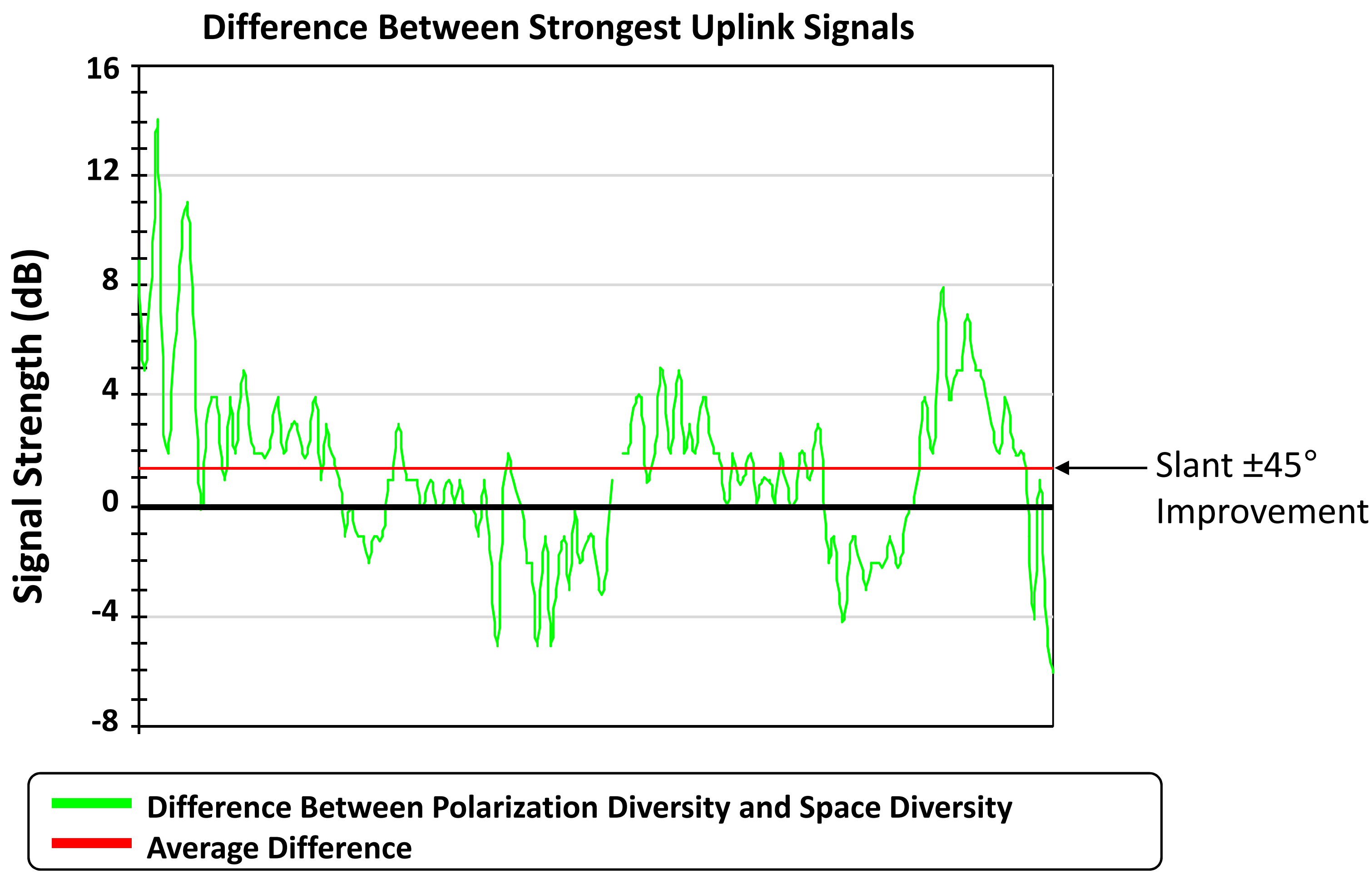
TEST 1A



Slant 45° / Hand-Held In Car

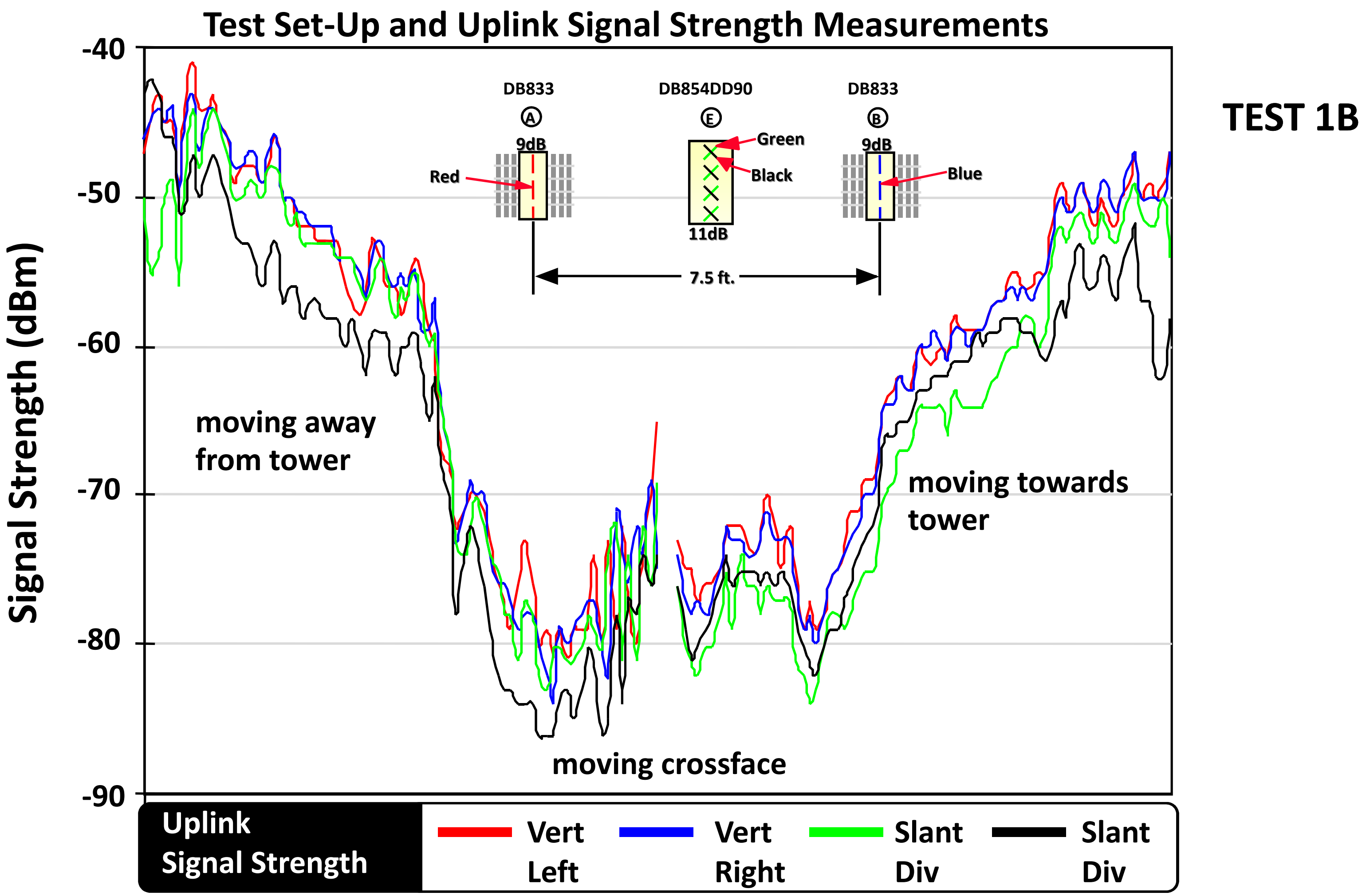
Space Diversity vs. Slanted +45°/–45°

TEST 1A



Slant 45° / Mobile With Glass Mount

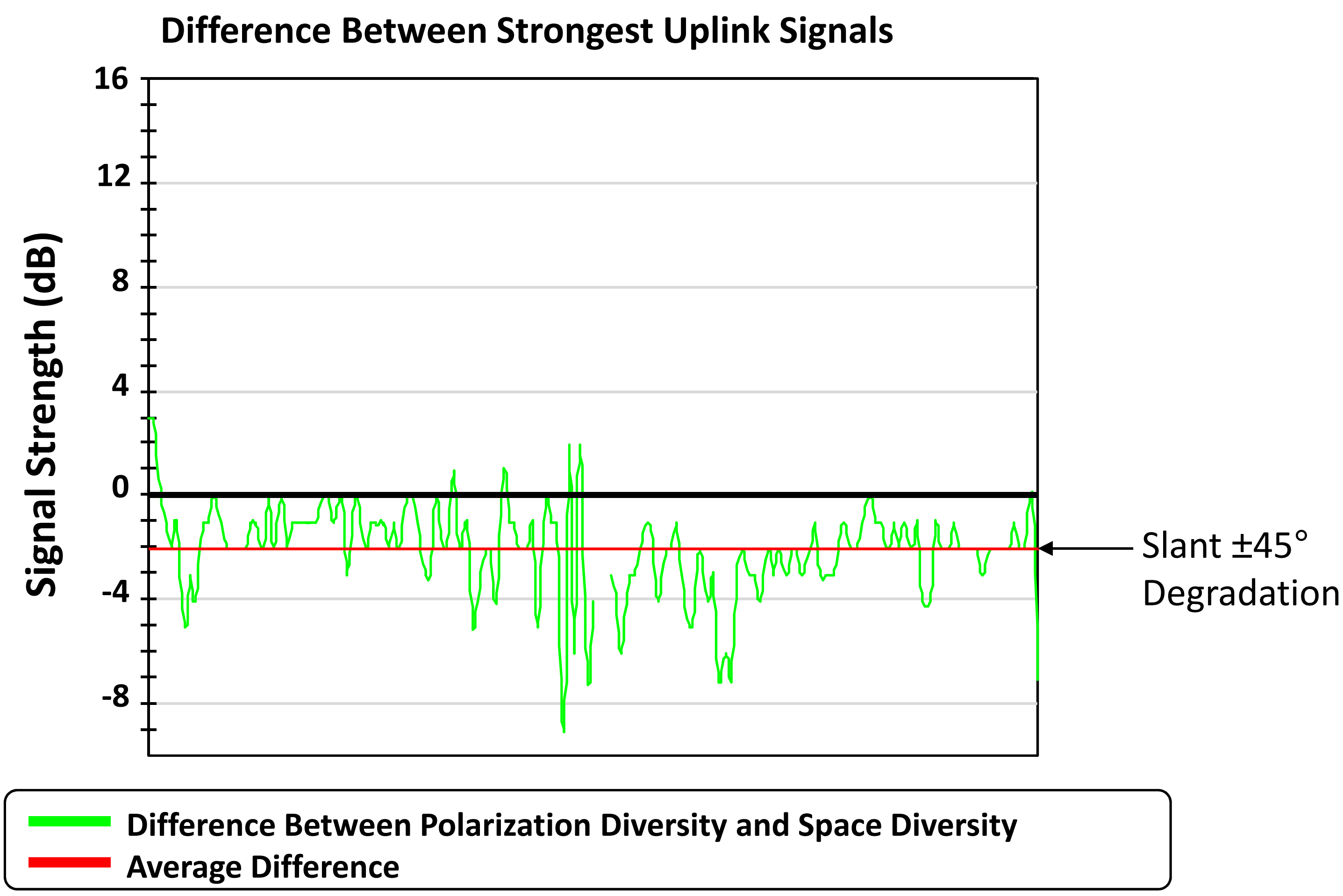
Space Diversity vs. Slanted +45°/–45°



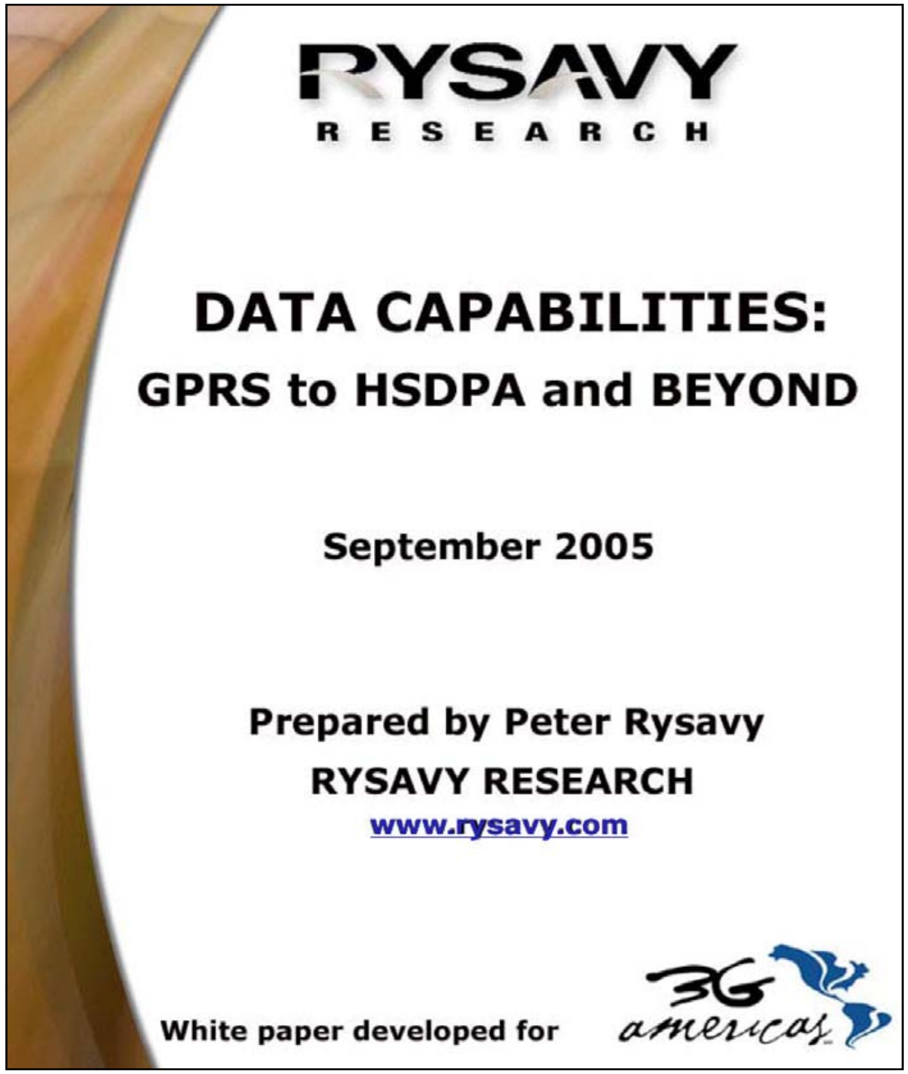
Slant 45° / Mobile With Glass Mount

Space Diversity vs. Slanted +45°/–45°

TEST 1B



Rysavy Research



RYSAVY
RESEARCH

DATA CAPABILITIES:
GPRS to HSDPA and BEYOND

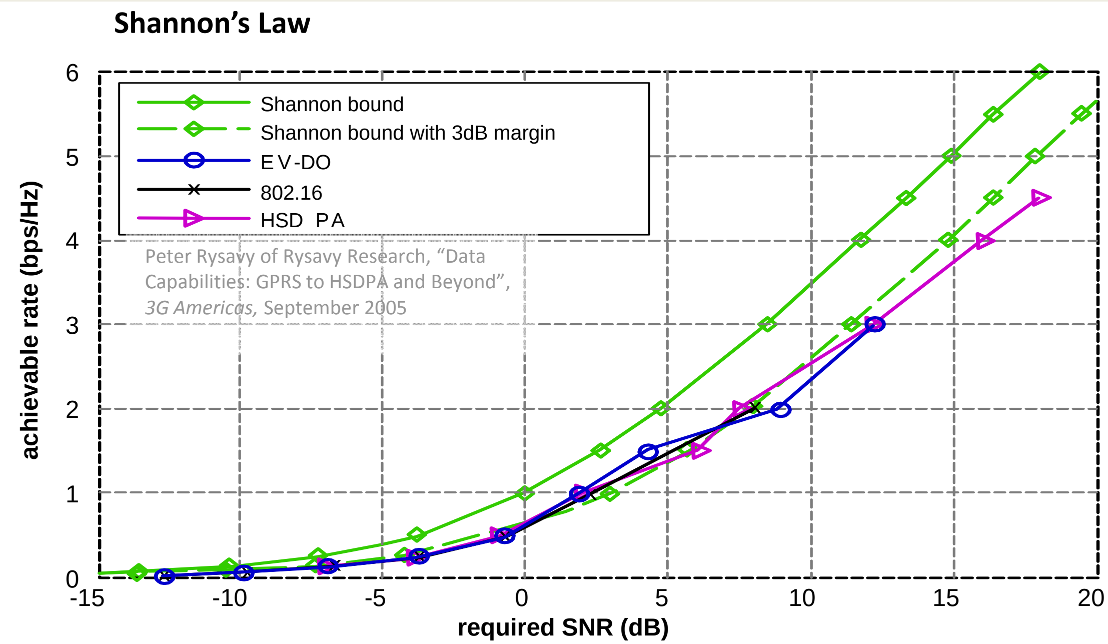
September 2005

Prepared by Peter Rysavy
RYSAVY RESEARCH
www.rysavy.com

White paper developed for 3G americas

Future Technology Focus

- Figure 16 shows that HSDPA,1xEV-DO, and 802.16e are all within 2-3 dB of the Shannon bound, indicating that from a link layer perspective, there is not much room for improvement.
- This figure demonstrates that the focus of future technology enhancements should be on improving system performance aspects that improve and maximize the experienced SNRs in the system instead of investigating new air interfaces that attempt to improve the link layer performance.



The focus of future technology enhancements should be on improving system performance aspects that improve and maximize the experienced SNRs in the system.

Peter Rysavy of Rysavy Research, *Data Capabilities: GPRS to HSDPA and Beyond*, 3G Americas, September 2005

[1] Peter Rysavy of Rysavy Research, "Data Capabilities: GPRS to HSDPA and Beyond", *3G Americas,* September 2005

The Impact

Lower Co-Channel Interference/Better Capacity And Quality

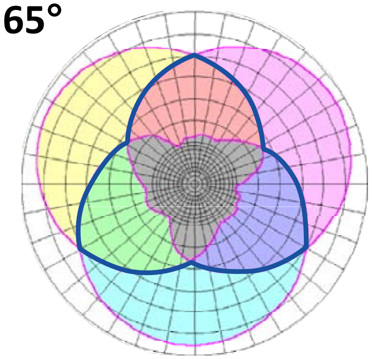
In a three sector site, traditional antennas produce a high degree of imperfect power control or sector overlap.

Imperfect sectorization presents opportunities for:

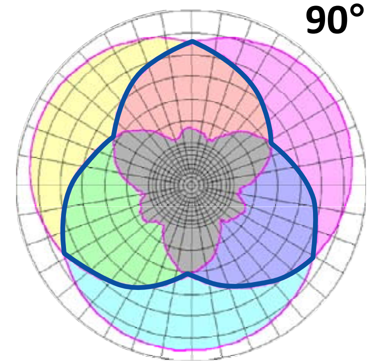
- Increased softer hand-offs
- Interfering signals
- Dropped calls
- Reduced capacity

Traditional Flat Panels

65°



90°

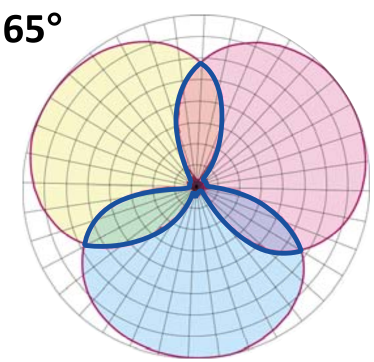


The rapid roll-off of the lower lobes of the Andrew Directed Dipole™ antennas create larger, better defined 'cones of silence'
behind the array.

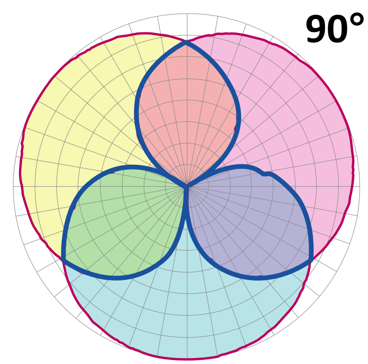
- Much smaller softer hand-off area
- Dramatic call quality improvement
- 5%–10% capacity enhancement

Andrew Directed Dipole™

65°



90°



120° Sector Overlay Issues

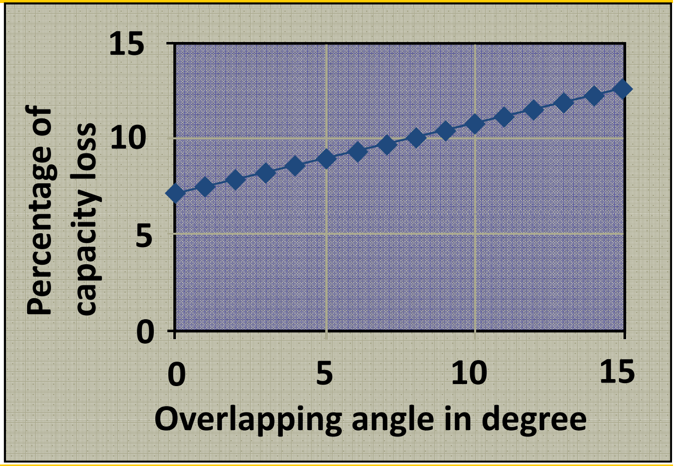
On the Capacity and Outage Probability of a CDMA Heirarchial Mobile System with Perfect/Imperfect Power Control and Sectorization

By: Jie ZHOU et, al IEICE TRANS FUNDAMENTALS, VOL.E82-A, NO.7 JULY 1999

. . . From the numerical results, the user capacities are dramatically decreased as the imperfect power control increases and the overlap between the sectors (imperfect sectorization) increases . . .

Effect of Soft and Softer Handoffs on CDMA System Capacity

By: Chin-Chun Lee et, al IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 47, NO. 3, AUGUST 1998

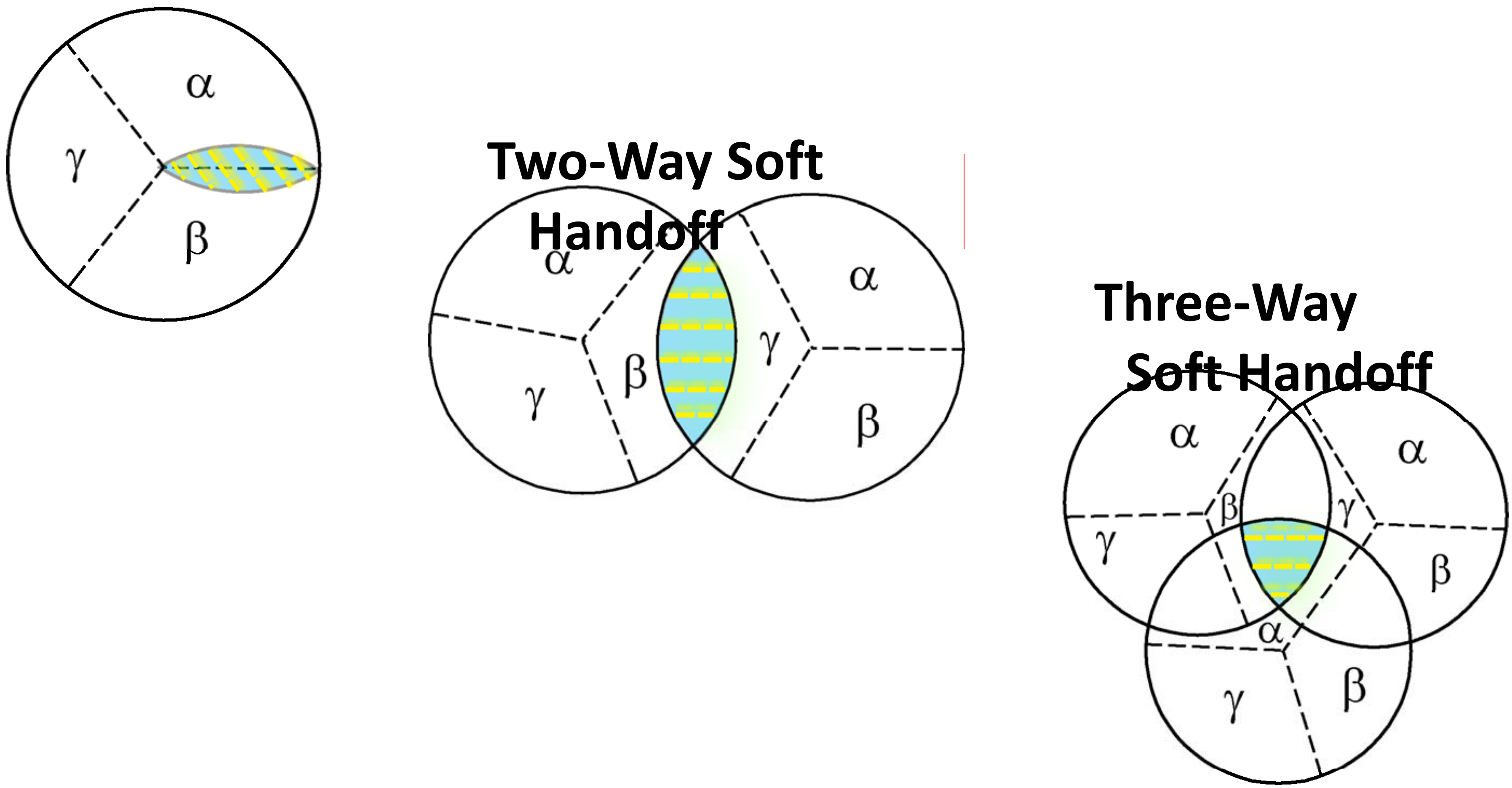


Qualitatively, excessive overlay also reduces capacity of TDMA and GSM systems.

Hard, Soft, and Softer Handoffs

- Hard Handoff
  - Used in time division multiplex systems
  - Switches from one frequency to another
  - Often results in a *ping-pong* switching effect
- Soft Handoff
  - Used in code division multiplex systems
  - Incorporates a rake receiver to combine signals from multiple cells
  - Smoother communication without the *clicks* typical in hard handoffs
- Softer Handoff
  - Similar to soft handoff except combines signals from multiple adjacent sectors

Soft and Softer Handoff Examples



Beam Downtilt

In urban areas, service and frequency utilization are frequently improved by directing maximum radiation power at an area below the horizon.

This technique . . .

- Improves coverage of open areas close to the base station.
- Allows more effective penetration of nearby buildings, particular high-traffic lower levels and garages.
- Permits the use of adjacent frequencies in the same general region.

Electrical/Mechanical Downtilt

- Mechanical downtilt lowers main beam, raises back lobe.
- Electrical downtilt lowers main beam and lowers back lobe.
- A combination of equal electrical and mechanical downtilts lowers main beam and brings back lobe onto the horizon!

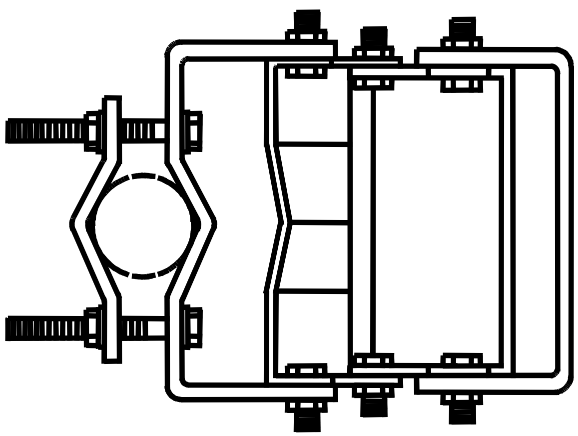
Electrical/Mechanical Downtilt (Continued)

Mechanical

Electrical

DB5083 Downtilt Mounting Kit

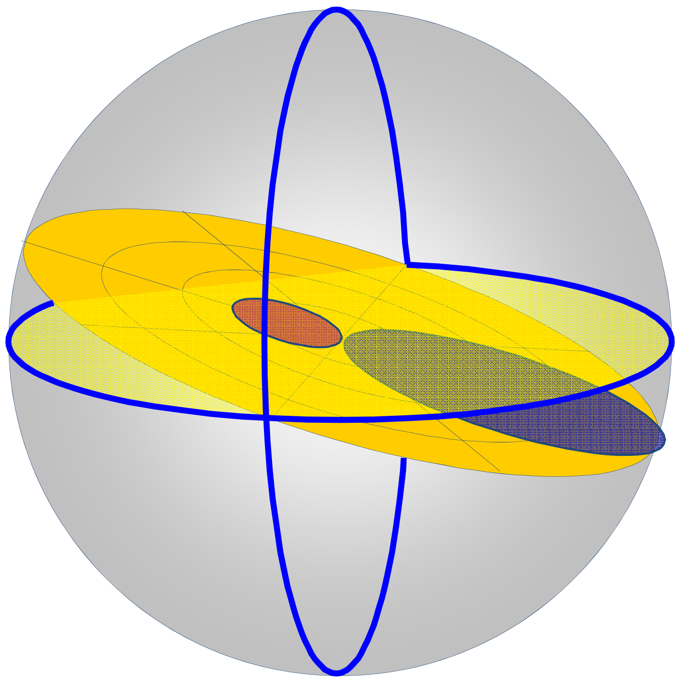
DB5083 downtilt mounting kit is
constructed of heavy duty galvanized steel,
designed for pipe mounting
12” to 20” wide panel antennas.



- Correct bracket calibration assumes a plumb mounting pipe!
- Check antenna with a digital level.

Mechanical Downtilt

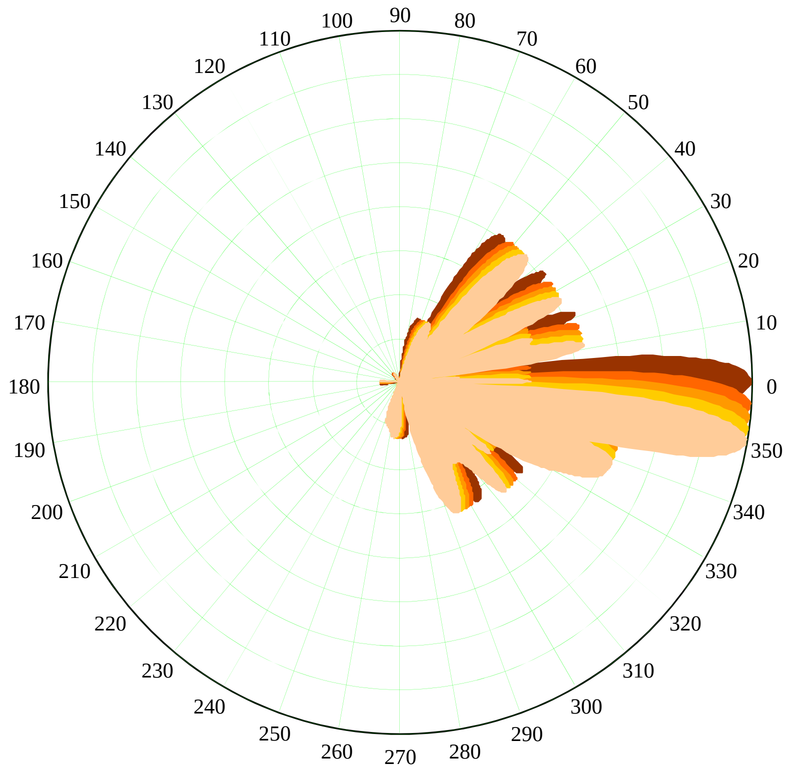
Pattern Analogy—Rotating A Disk



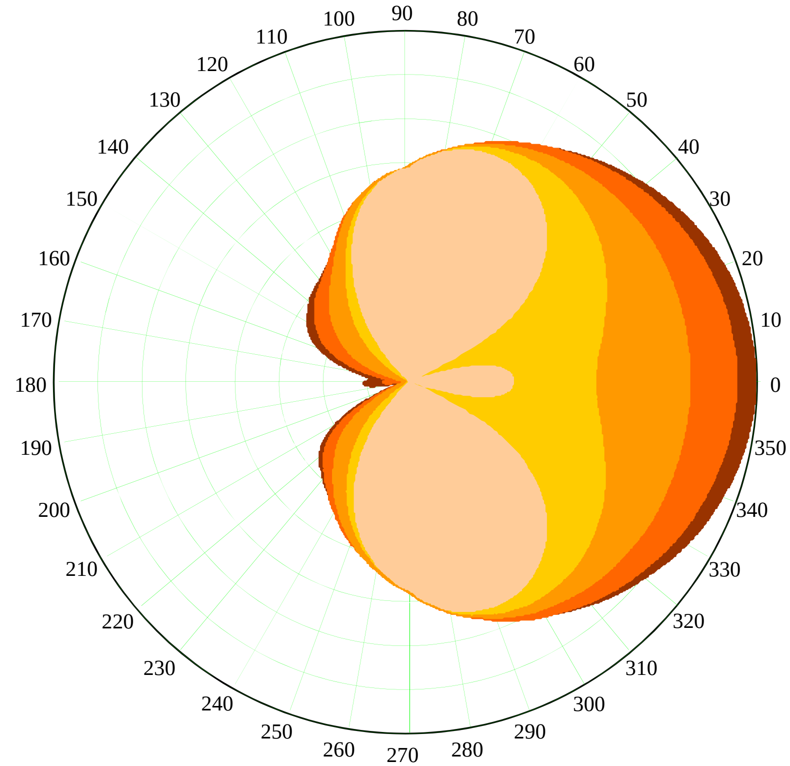
Mechanical tilt causes . . .

- Beam peak to tilt below horizon
- Back lobe to tilt above horizon
- At ± 90°, no tilt

Mechanical Downtilt Coverage



Elevation Pattern



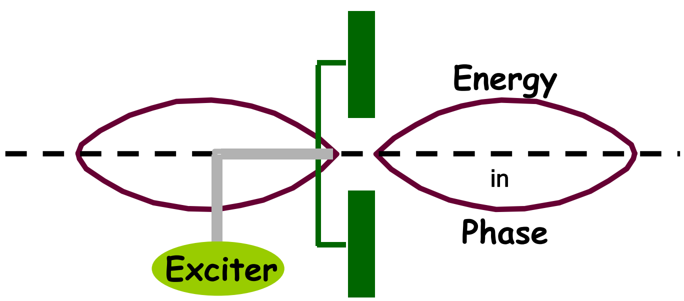
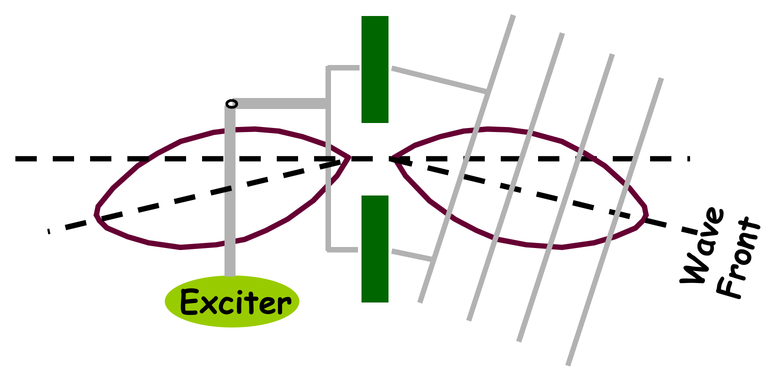
Azimuth Pattern

Mechanical Tilt	0°	4°	6°	8°	10°

Managing Beam Tilt

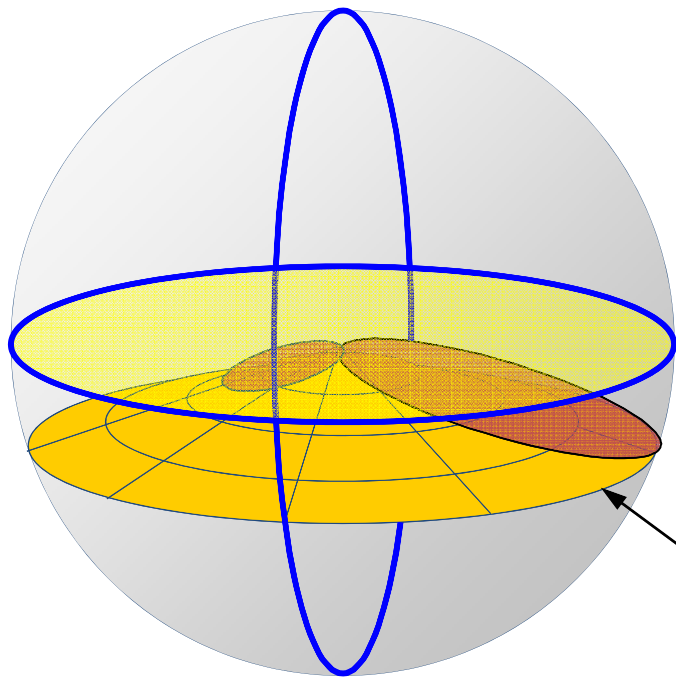
- For the radiation pattern to show maximum gain in the direction of the horizon, each stacked dipole must be fed from the signal source *in phase*.
- Feeding vertically arranged dipoles *out of phase* will generate patterns that *look up* or *look down*.
- The degree of beam tilt is a function of the phase shift of one dipole relative to the adjacent dipole.

Generating Beam Tilt

Dipoles Fed *In Phase*	Dipoles Fed *Out of Phase*
	

Electrical Downtilt

Pattern Analogy—Forming A Cone Out Of A Disk

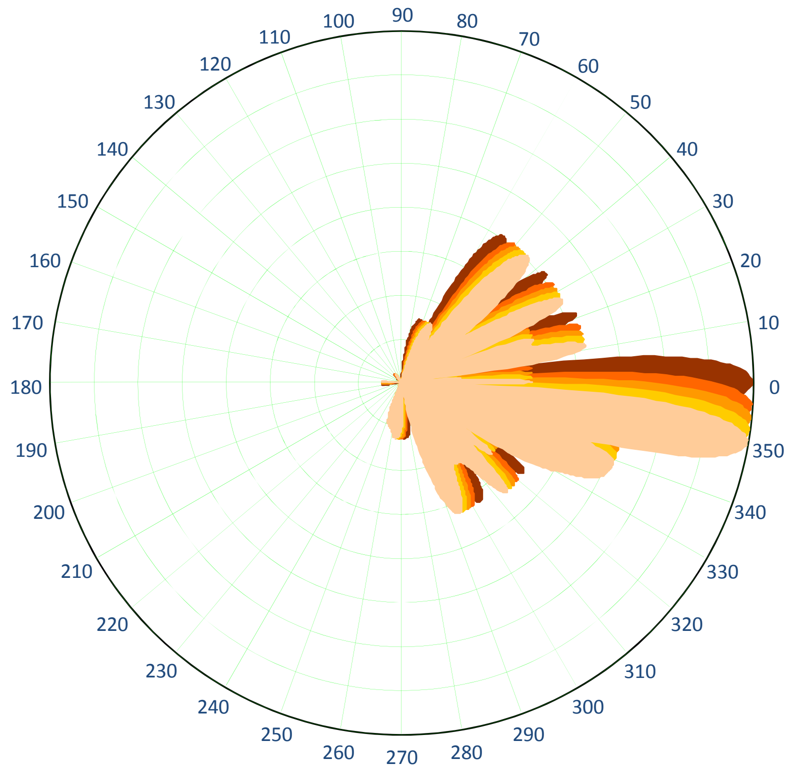


Cone of the
Beam Peak Pattern

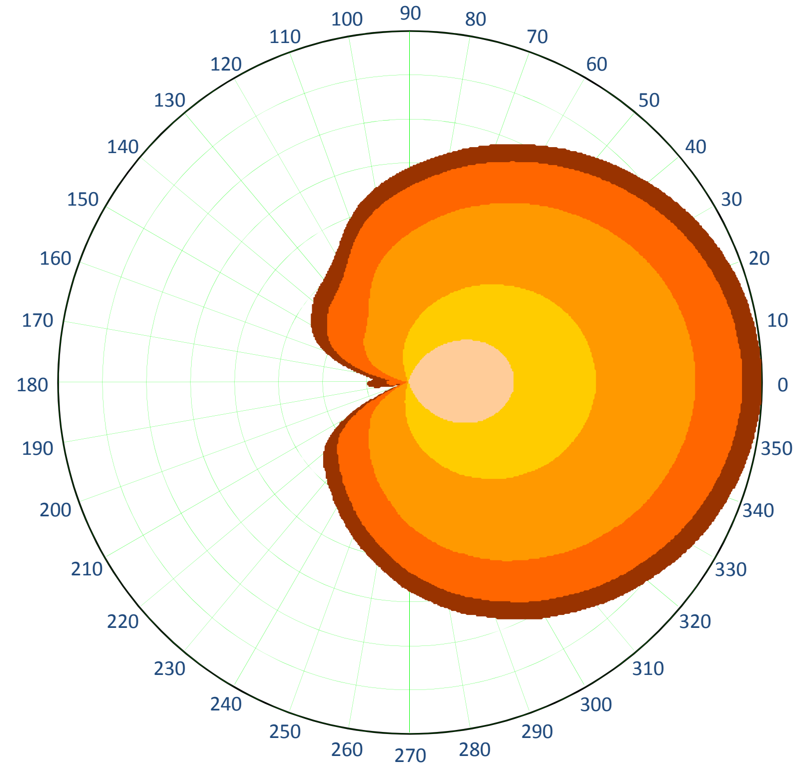
Electrical tilt causes . . .

- Beam peak to tilt below horizon
- Back lobe to tilt below horizon
- At ± 90°, tilt below horizon
- All the pattern tilts

Electrical Downtilt Coverage



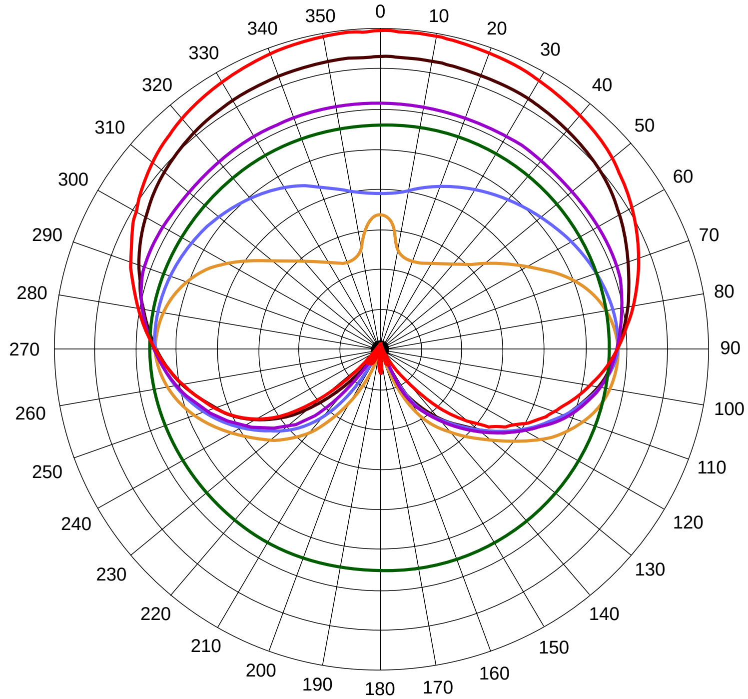
Elevation Pattern



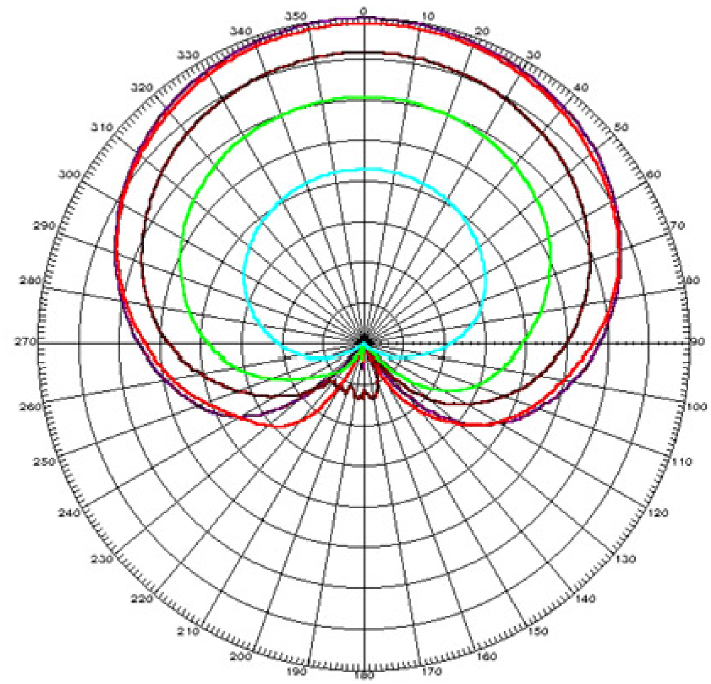
Azimuth Pattern

Electrical Tilt	0°	4°	6°	8°	10°

Mechanical Vs. Electrical Downtilt

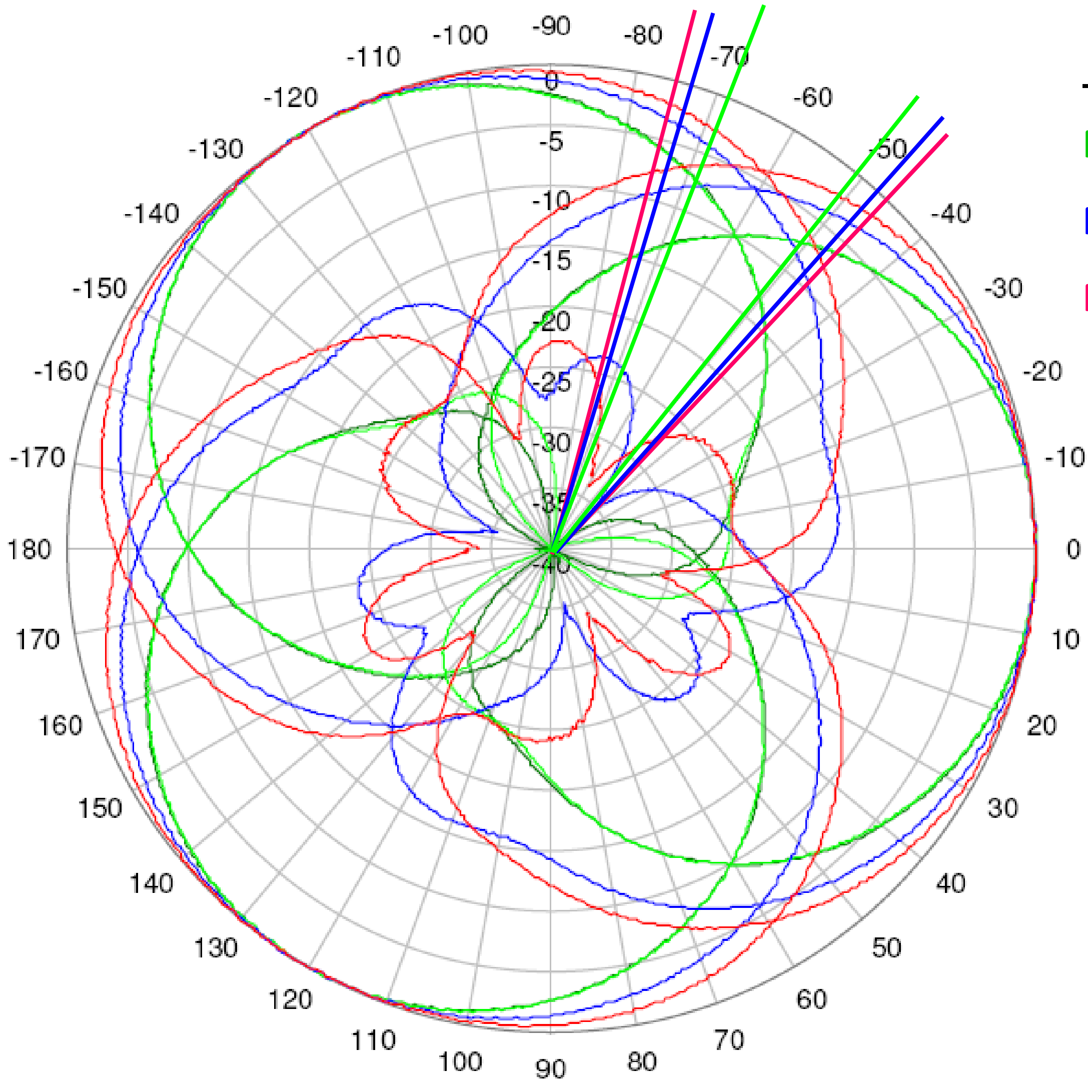


Mechanical



Electrical

Effects of Blooming on Sector ce



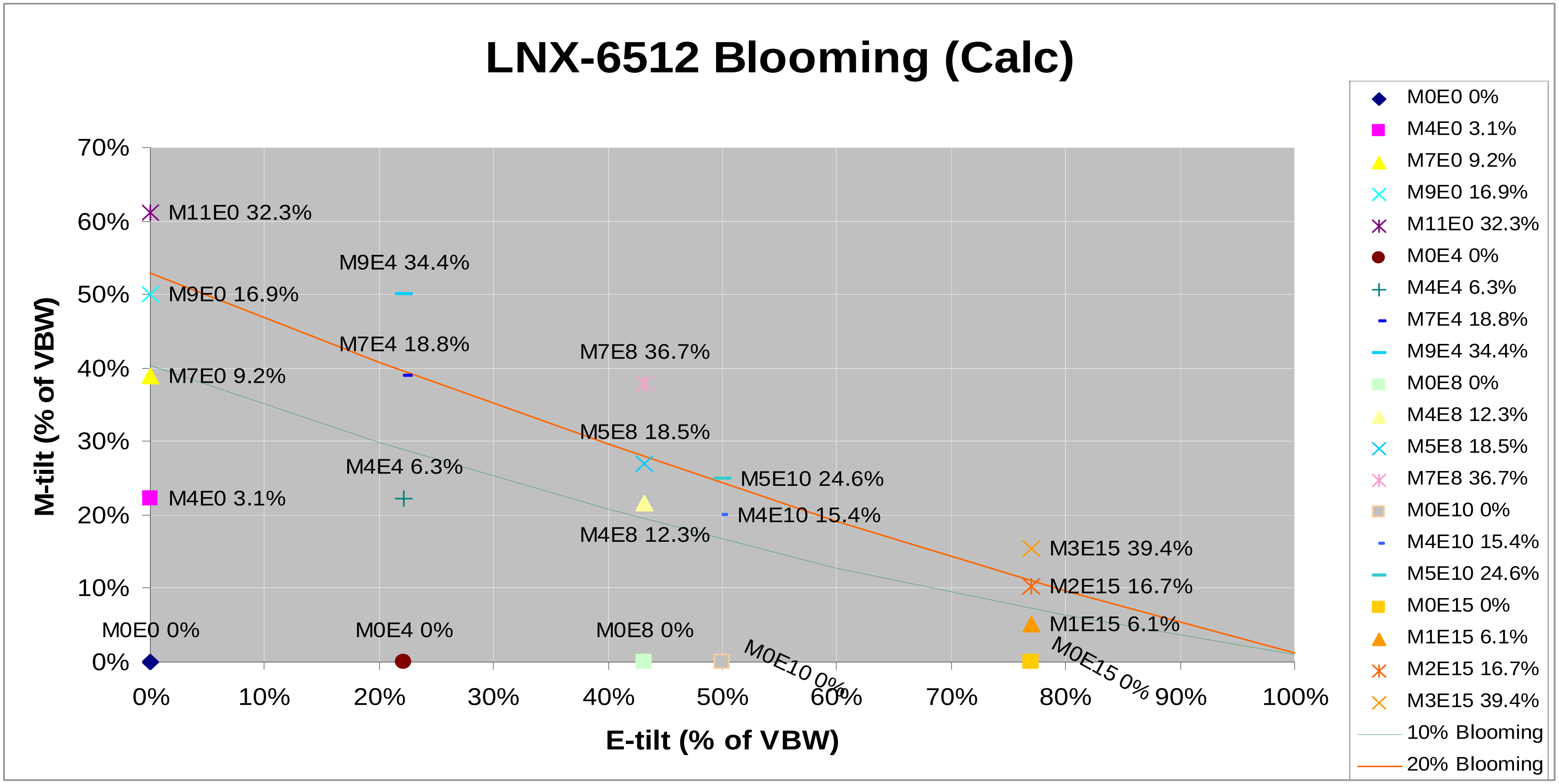
M( )E( ) Tilt	Angle	Crossover
M0E0 & M0E7 ----	17°	10 dB
M7E7 ----------------	25°	6 dB
M14E0 --------------	29°	4 dB

Legend Table

No.	Color	Dataset Name
1		RP_C_X_M=0_E=0
2		RP_C_X_M=0_E=0
3		RP_C_X_M=0_E=0
4		RP_C_X_M=0_E=7
5		RP_C_X_M=0_E=7
6		RP_C_X_M=0_E=7
7		RP_C_X_M=7_E=7
8		RP_C_X_M=7_E=7
9		RP_C_X_M=7_E=7
10		RP_C_X_M=14_E=0
11		RP_C_X_M=14_E=0
12		RP_C_X_M=14_E=0

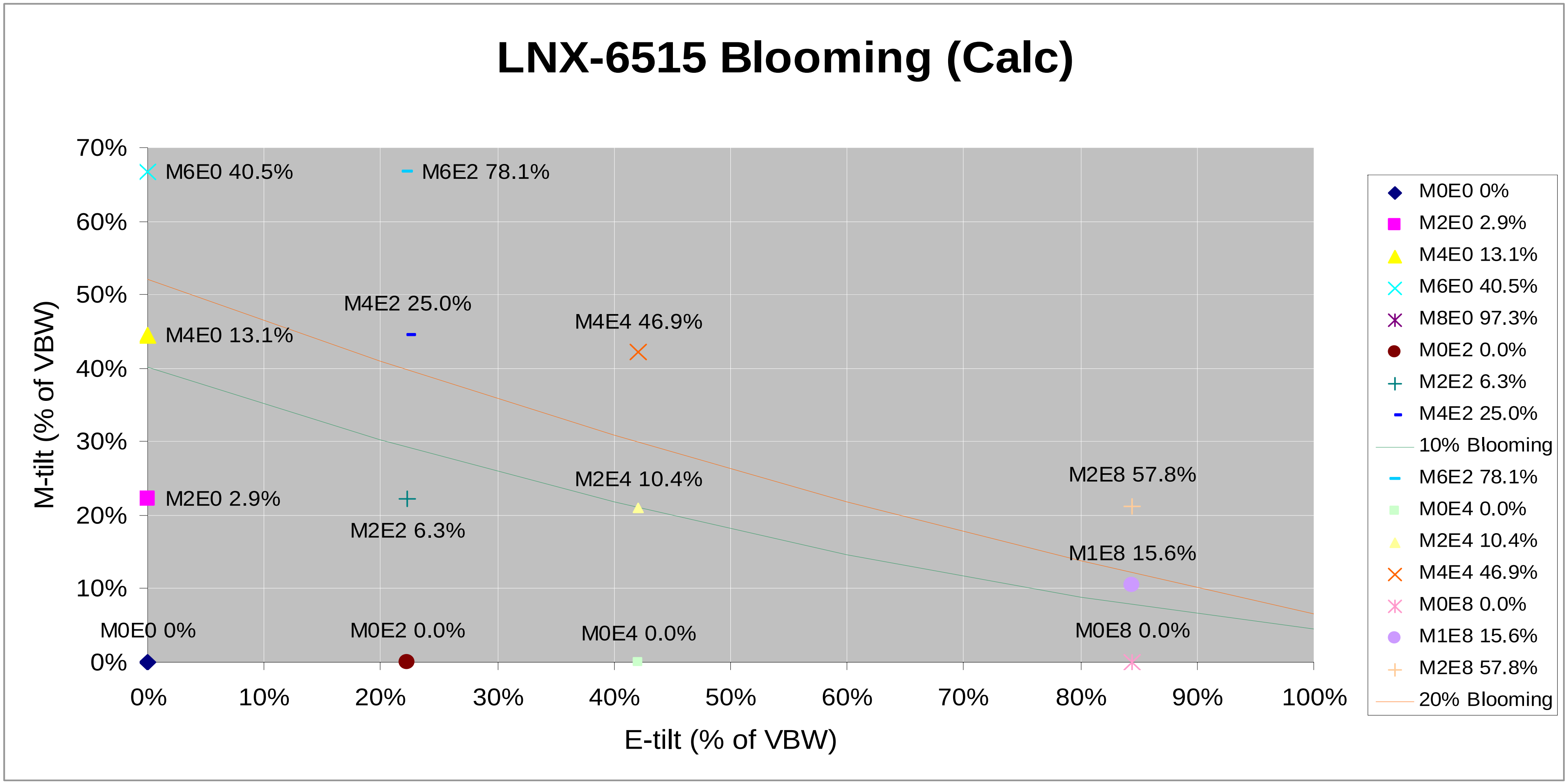
Combined Electrical and Mechanical Tilt

4 Foot Antenna at 780 MHz



Combined Electrical and Mechanical Tilt

8 Foot Antenna at 780 MHz



Modified "Rules of Thumb" for 10% Blooming

To insure that the azimuth pattern of a typical antenna - as viewed on the horizon - does not bloom by more than 10%, never mechanically downtilt a given antenna more than the amount calculated by the equations below:

$$65º\ HBW\ M\text{-}tilt_{10\%\ Bloom} = (VBW - E\text{-}tilt)/2.5$$

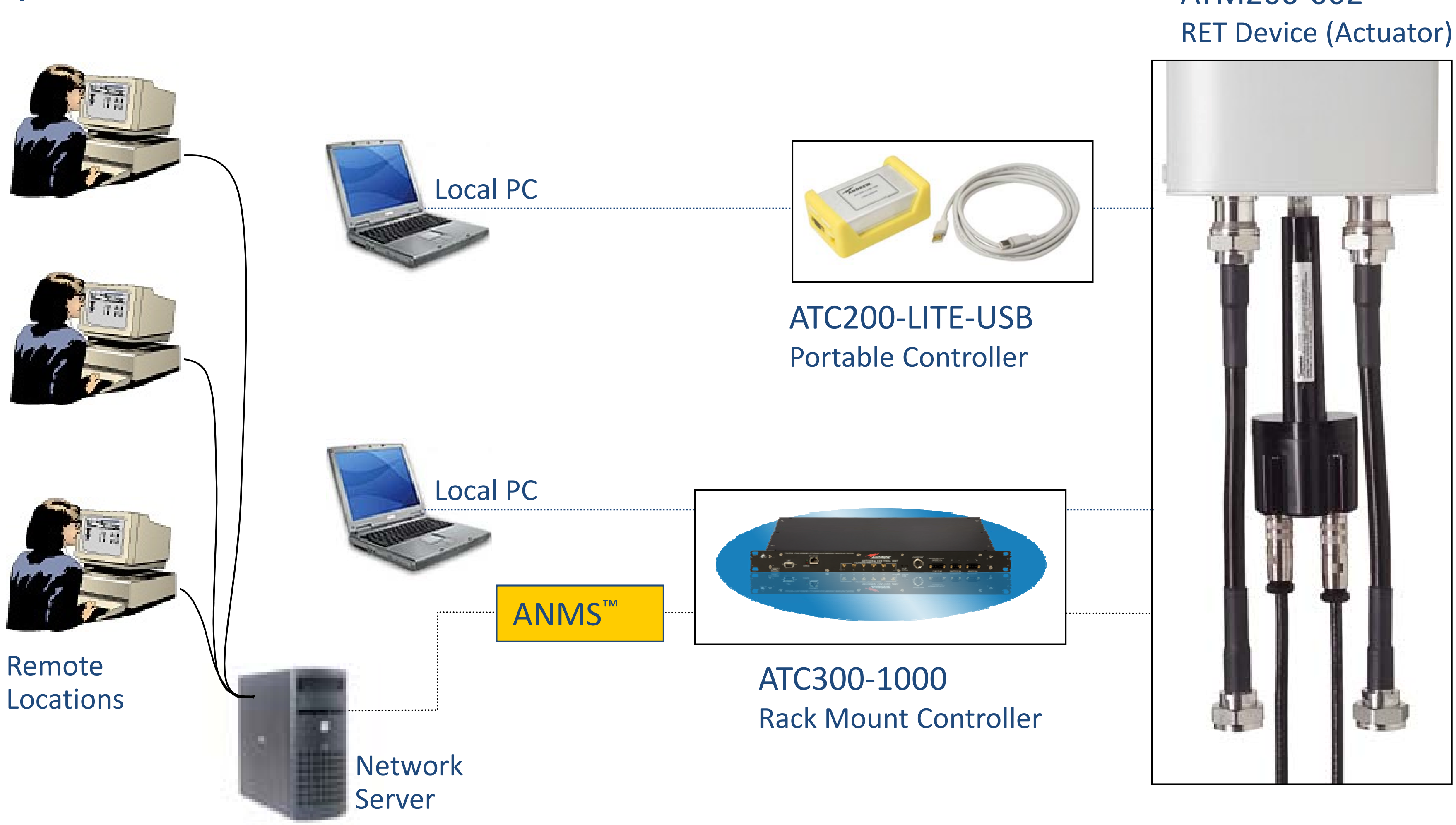
Other HBW antennas follow different rules:

$$33º\ HBW\ M\text{-}tilt_{10\%\ Bloom} = (VBW - E\text{-}tilt)/1.5$$

$$90º\ HBW\ M\text{-}tilt_{10\%\ Bloom} = (VBW - E\text{-}tilt)/3.3$$

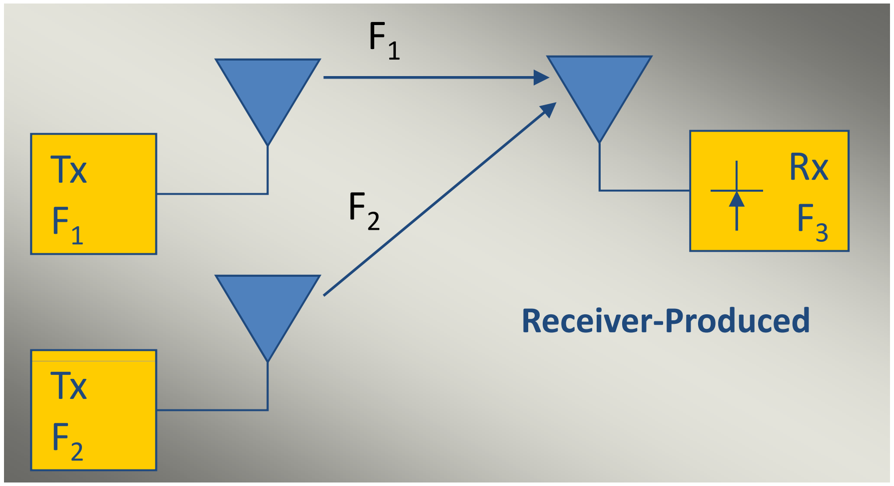
Remote Electrical Downtilt (RET)

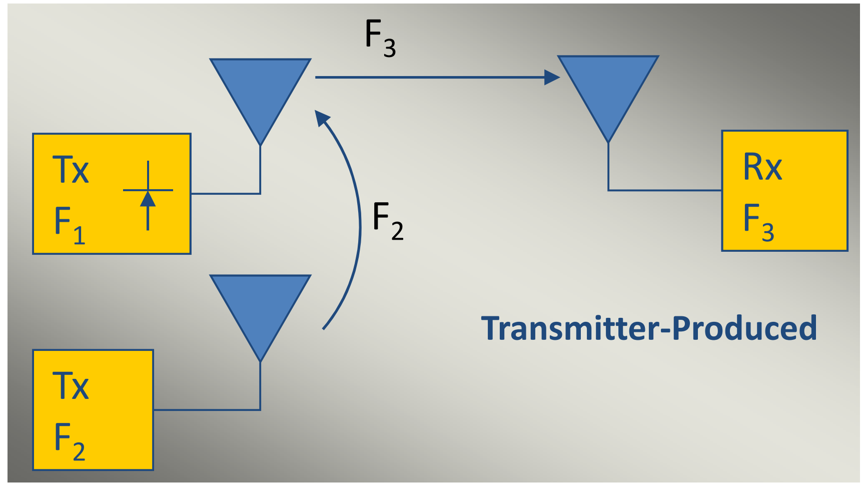
Optimization

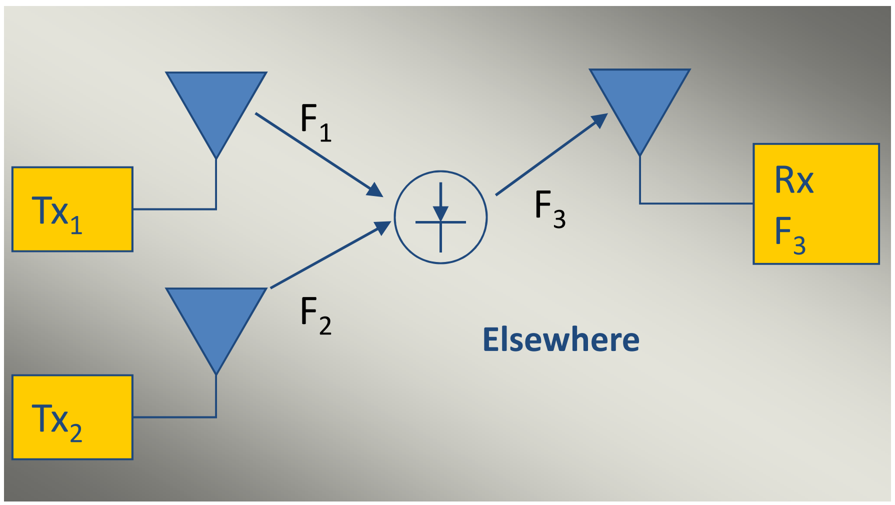


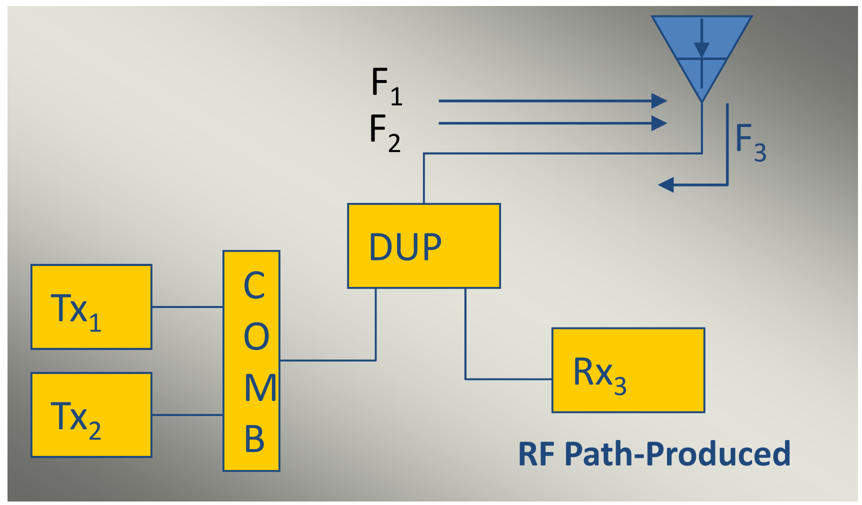
Intermod Interference

Where?









High Band

Product Frequencies, Two-Signal IM

$F_{IM} = nF_1 \pm mF_2$
Example: F_1 = 1945 MHz; F_2 = 1930 MHz

n	m	Product Order	Product Formulae	Product Frequencies (MHz)
1	1	Second	$1F_1 + 1F_2$ $1F_1 - 1F_2$	3875 15
2	1	Third	$2F_1 + 1F_2$ $*2F_1 - 1F_2$	5820 1960
1	2	Third	$2F_2 + 1F_1$ $*2F_2 - 1F_1$	5805 1915
2	2	Fourth	$2F_1 + 2F_2$ $2F_1 - 2F_2$	7750 30
3	2	Fifth	$3F_1 + 2F_2$ $*3F_1 - 2F_2$	9695 1975
2	3	Fifth	$3F_2 + 2F_1$ $*3F_2 - 2F_1$	9680 1900

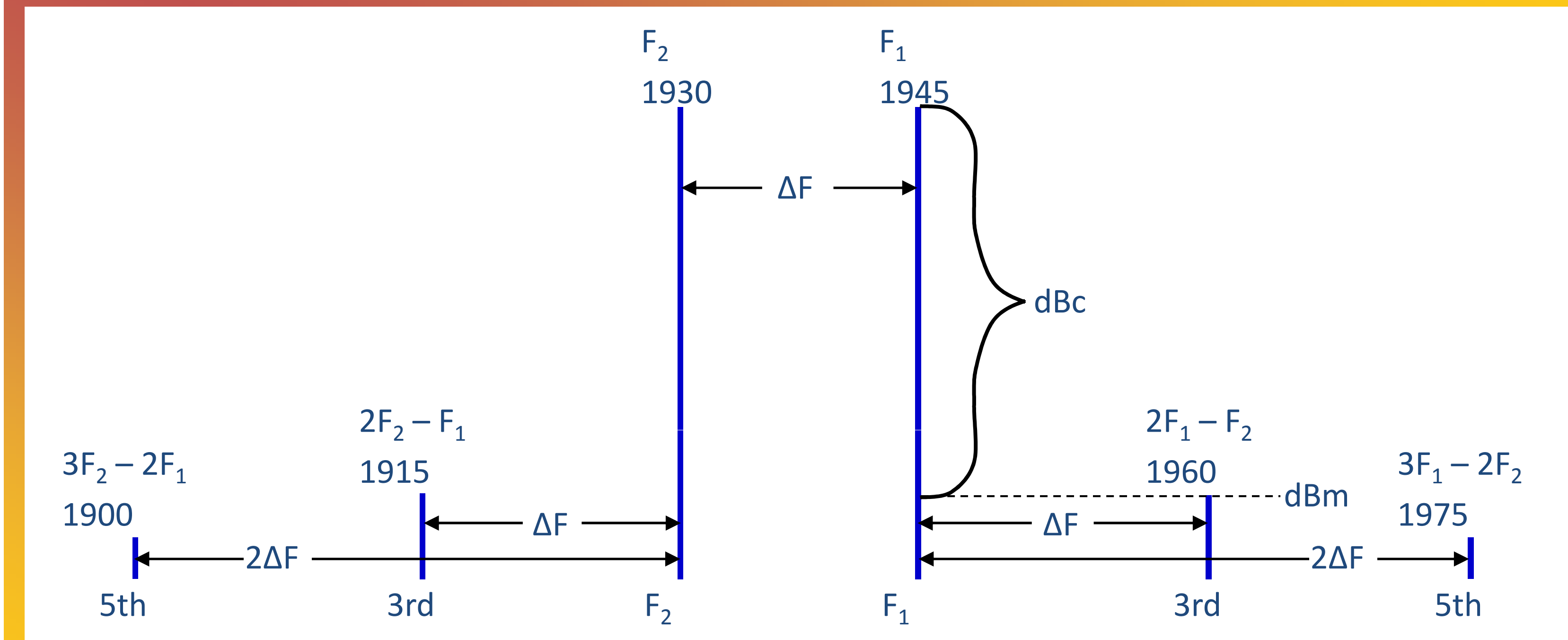
*Odd-order difference products fall in-band.

Two-Signal IM

Odd-Order Difference Products

Example: F_1 = 1945 MHz; F_2 = 1930 MHz

$\Delta F = F_1 - F_2 = 15$



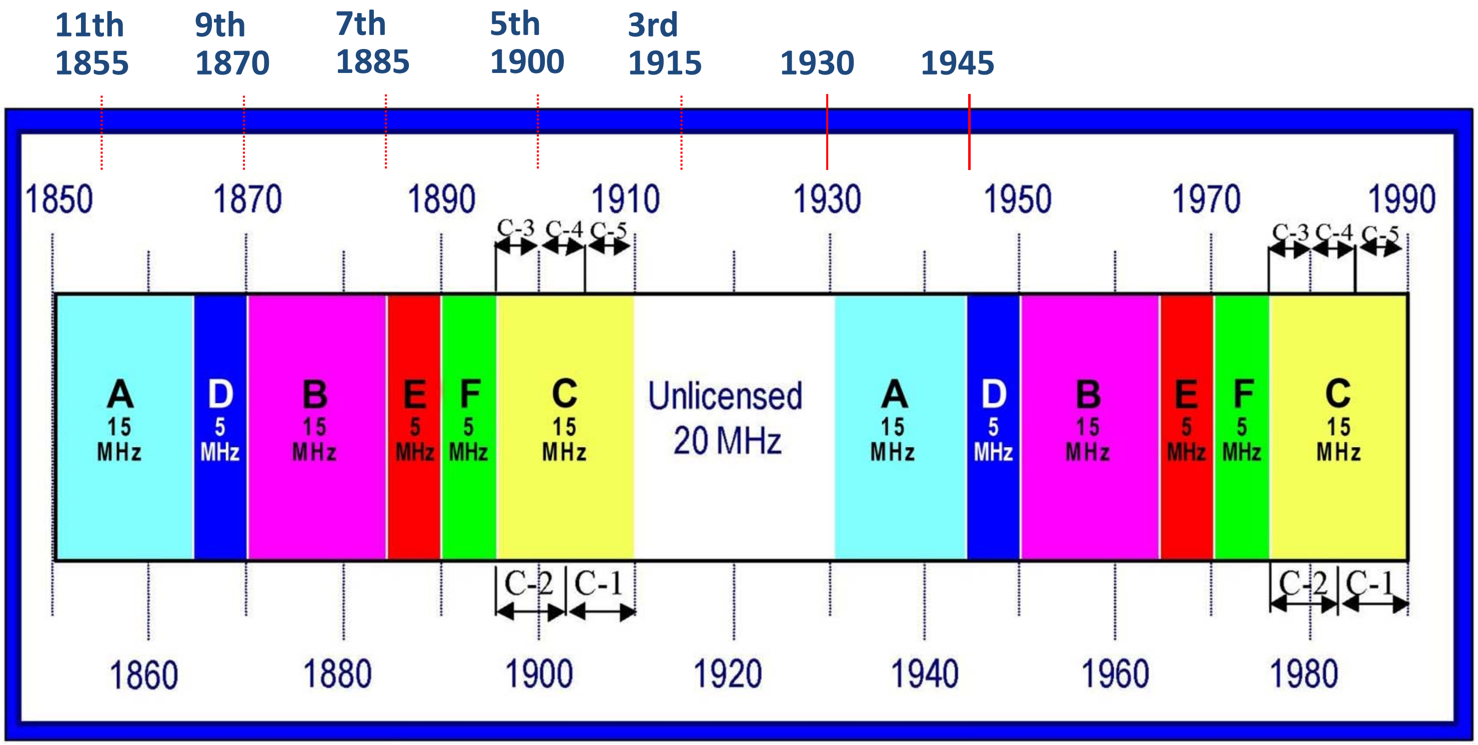
Third Order: $F_1 + \Delta F$; $F_2 - \Delta F$

Fifth Order: $F_1 + 2\Delta F$; $F_2 - 2\Delta F$

Seventh Order: $F_1 + 3\Delta F$; $F_2 - 3\Delta F$

Higher than the highest – lower than the lowest – none in-between

PCS A Band Intermodulation

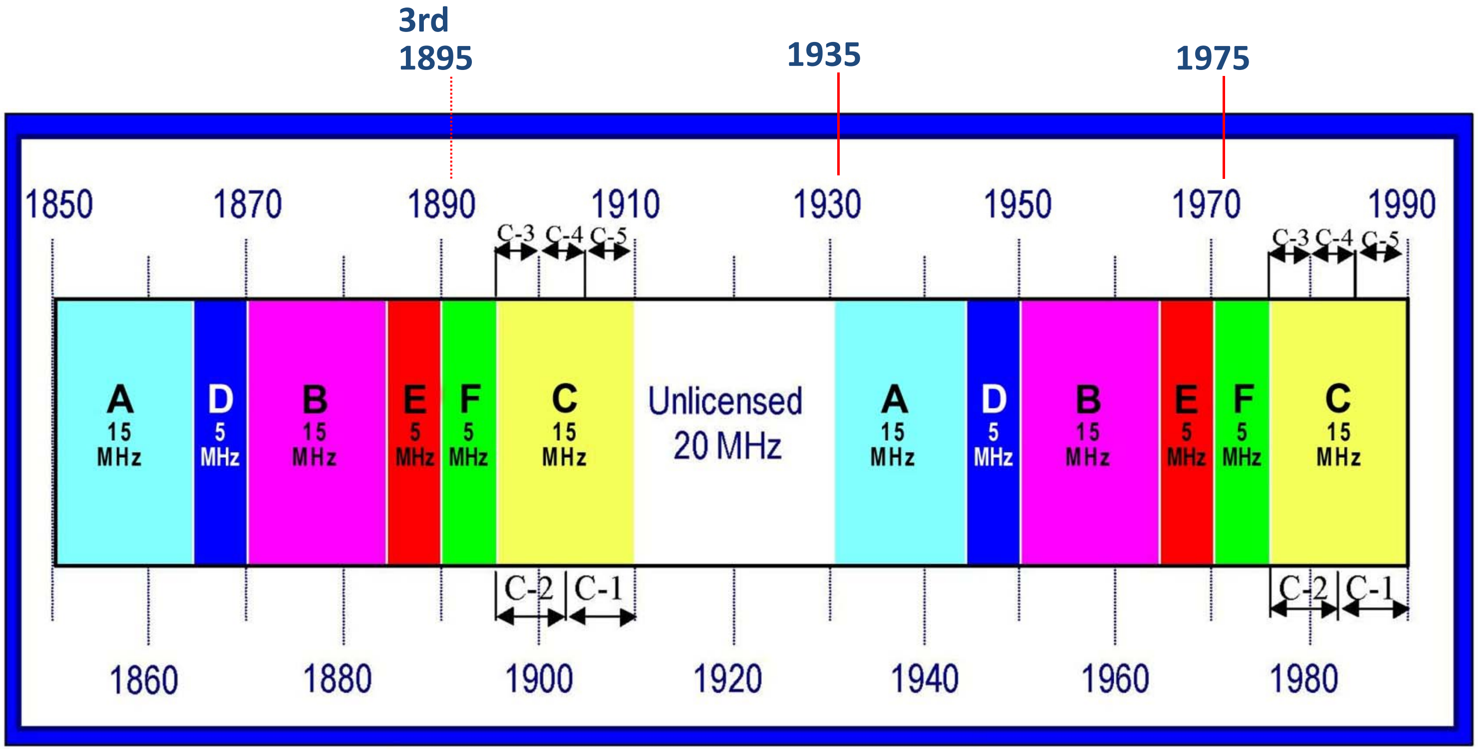


Channel Block	Bandwidth (MHz)	Frequencies
C	30	1895–1910, 1975–1990
C1	15	1902.5–1910, 1982.5–1990
C2	15	1895–1902.5, 1975–1982.5
C3	10	1895–1900, 1975–1980
C4	10	1900–1905, 1980–1985
C5	10	1905–1910, 1985–1990

FCC Broadband PCS Band Plan

Note: Some of the original C block licenses (originally 30 MHz each) were split into multiple licenses (C-1 and C-2: 15 MHz; C-3, C-4, and C-5: 10 MHz).

PCS A & F Band Intermodulation



Channel Block	Bandwidth (MHz)	Frequencies
C	30	1895–1910, 1975–1990
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C5	10	1905–1910, 1985–1990

FCC Broadband PCS Band Plan

Note: Some of the original C block licenses (originally 30 MHz each) were split into multiple licenses (C-1 and C-2: 15 MHz; C-3, C-4, and C-5: 10 MHz).

Causes Of IMD

- Ferromagnetic materials in the current path:
  - Steel
  - Nickel plating or underplating
- Current disruption:
  - Loosely contacting surfaces
  - Non-conductive oxide layers between contact surfaces

System VSWR Calculator

System VSWR Calculator

Version 9.0

18-Mar-09

ANDREW
A CommScope Company

Frequency (MHz):	850.00

Component Used?	System Component	Max. VSWR	Return Loss (dB)	Cable Type / Component Loss (dB)	Cable Length (m)	Cable Length (ft)	Ins Loss w/2 Conn (dB)	% of Est. System Reflection	Reflections at input
	Antenna or Load	1.50	13.98					87.2%	0.1003
No	**Jumper**	1.05	32.26		1.83	6.00	0.00	0.0%	0.0000
No	Tower Mounted Amp	1.20	20.83	0.20			0.00	0.0%	0.0000
No	Jumper	1.09	27.32		1.83	6.00	0.00	0.0%	0.0000
No	Top Diplexer or Bias Tee	1.15	23.13	0.20			0.00	0.0%	0.0000
No	Jumper	1.09	27.32		1.83	6.00	0.00	0.0%	0.0000
No	**Main Feed Line**	1.07	29.42		200.00	656.17	0.00	0.0%	0.0000
No	**Jumper**	1.09	27.32		30.48	100.00	0.00	0.0%	0.0000
No	Bias Tee	1.15	23.13	0.10			0.00	0.0%	0.0000
No	Jumper	1.09	27.32		1.83	6.00	0.00	0.0%	0.0000
No	**Surge Suppressor**	1.07	29.42	0.10			0.00	0.0%	0.0000
No	Jumper	1.09	27.32		1.83	6.00	0.00	0.0%	0.0000
No	Bottom Diplexer or Duplexer	1.20	20.83	0.10			0.00	0.0%	0.0000
Yes	**Jumper**	1.08	28.30	FSJ4-50B	27.30	89.57	3.00	12.8%	0.0385
								100.0%	

Legacy Jumper / TL Cables	Andrew	CommScope
1/2 inch Superflexible Copper	FSJ4-50B	
1/2 inch Foam Copper	LDF4-50A	CR 540
1/2 inch Superflexible Aluminum		SFX 500
1/2 inch Foam Aluminum		FXL 540

Legacy Transmission Lines	Andrew	CommScope
7/8 inch Copper	LDF5-50A	CR 1070
1 1/4 inch Copper	LDF6-50	CR 1480
1 5/8 inch Copper	LDF7-50A	CR 1873
7/8 inch Very Flexible Copper	VXL5-50	
1 1/4 inch Very Flexible Copper	VXL6-50	
1 5/8 inch Very Flexible Copper	VXL7-50	
7/8 inch Virtual Air Copper	AVA5-50	
1 5/8 inch Virtual Air Copper	AVA7-50	
7/8 inch Aluminum	AL5-50	FXL 780
1 1/4 inch Aluminum		FXL 1480
1 5/8 inch Aluminum	AL7-50	FXL 1873

Estimated Conn Loss (2per cable)	0.028
Typical System Reflection:	0.1074
Typical System VSWR:	1.24
Typical System Return Loss (dB):	19.4
Worst System Reflection:	0.1387
Worst System VSWR:	1.32
Worst System Return Loss (dB):	17.2
Total Insertion Loss (dB):	3.00

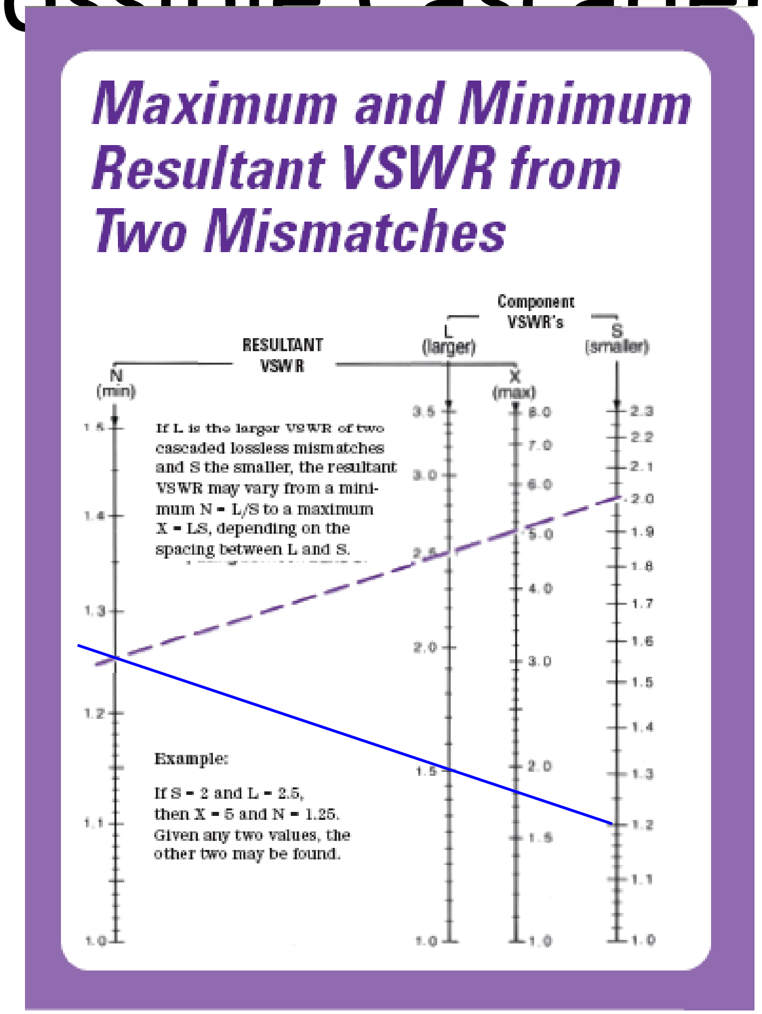
Return Loss to VSWR converter

Return Loss (dB)	VSWR
17.00	1.33

Feet to meters converter

Feet	meters
100.00	30.48

Possible Cascaded VSWR Results



Possible results (at a given frequency) when Antenna and TMA are interconnected with different *electrical* length jumpers.

If: L = 1.5:1 (14 dB RL Antenna)

S = 1.2:1 (20.8 dB RL TMA)

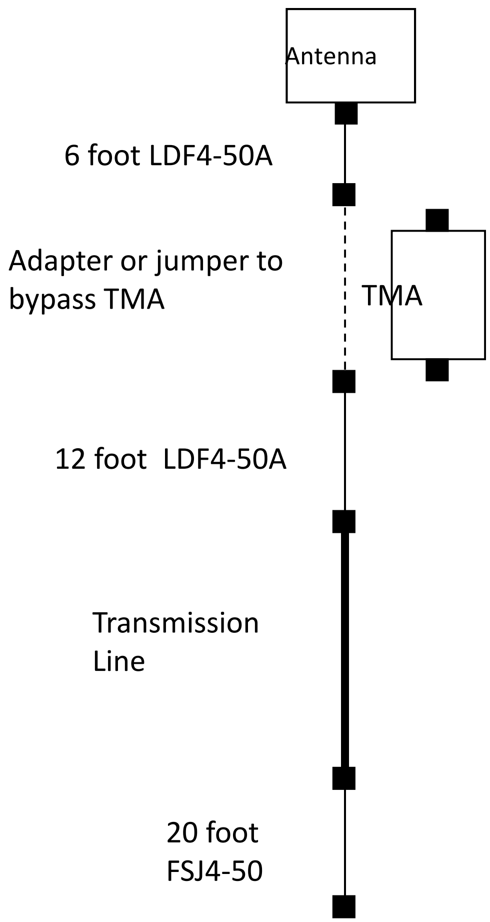
Then: X (max) = 1.8:1 (10.9 dB RL)

S (min) = 1.25:1 (19.1 dB RL)

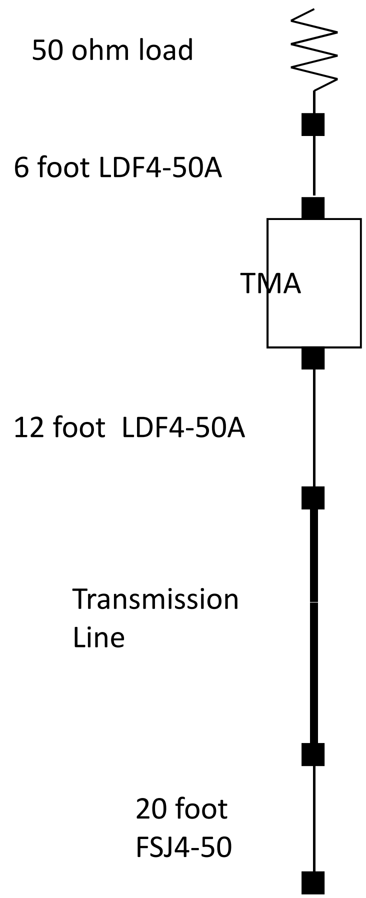
Worst case seldom happens in real life, but be aware that it is possible!

From http://www.home.agilent.com/agilent/editorial.jspx?cc=US&lc=eng&ckey=895674&nid=-35131.0.00&id=895674

Recommended Antenna/TMA Qualification Test

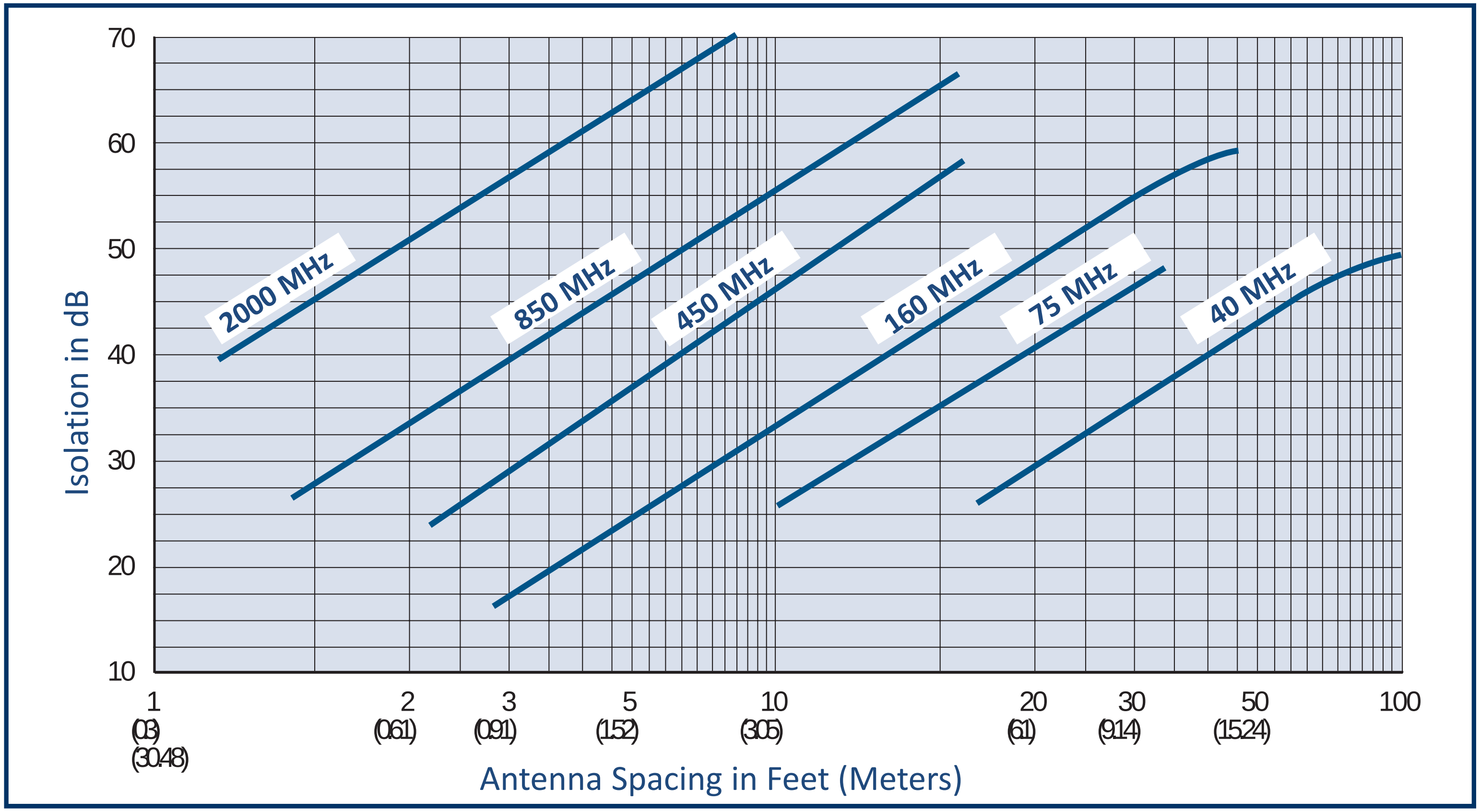


Antenna Return Loss Diagram



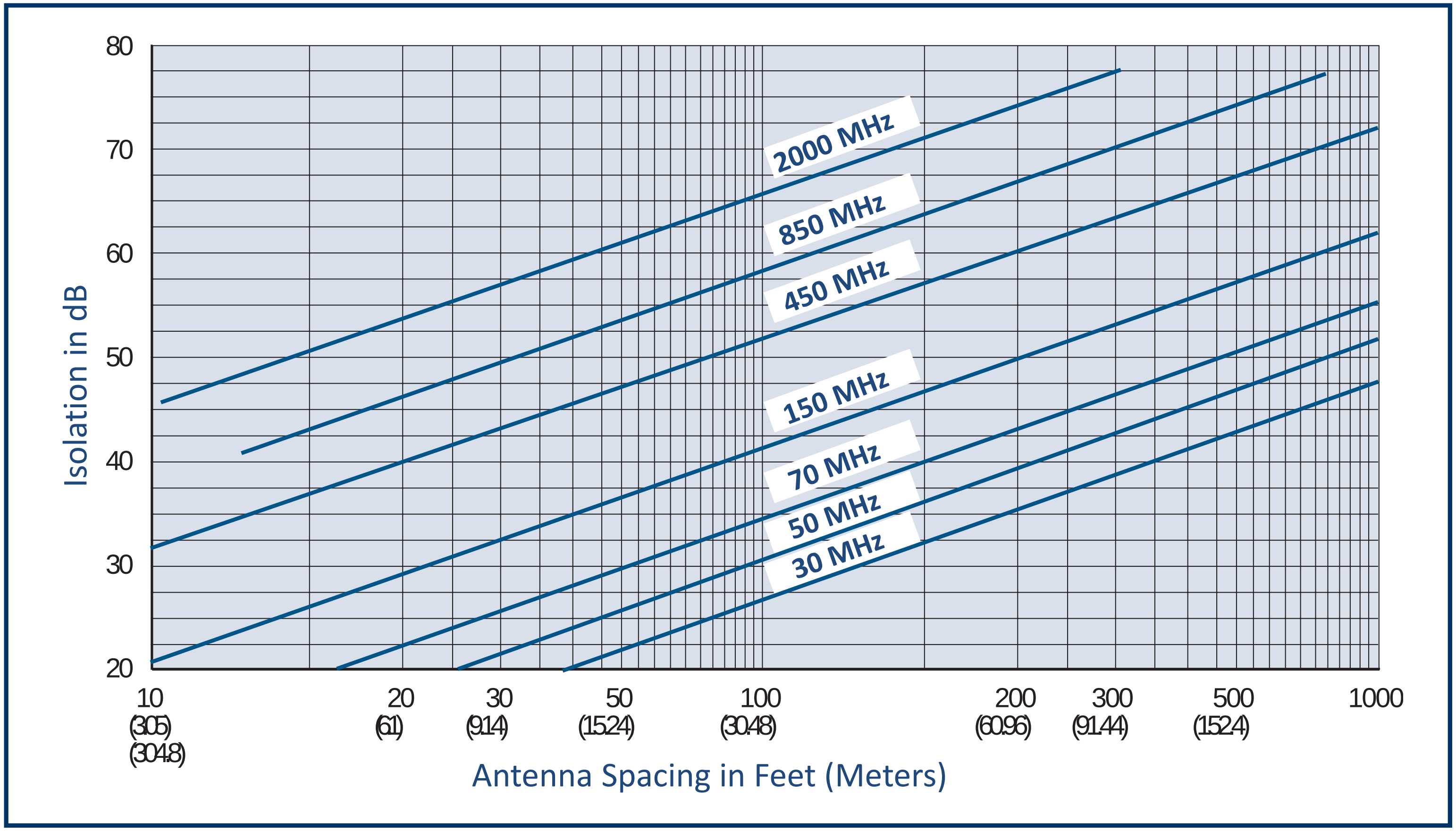
TMA Return Loss Diagram

Attenuation Provided By Vertical Separation Of Dipole Antennas



The values indicated by these curves are approximate because of coupling which exists between the antenna and transmission line. Curves are based on the use of half-wave dipole antennas. The curves will also provide acceptable results for gain type antennas. If values (1) the spacing is measured between the physical center of the tower antennas and it (2) one antenna is mounted directly above the other, with no horizontal offset collinear). No correction factor is required for the antenna gains.

Attenuation Provided By Horizontal Separation Of Dipole Antennas



Curves are based on the use of half-wave dipole antennas. The curves will also provide acceptable results for gain type antennas if (1) the indicated isolation is reduced by the sum of the antenna gains and (2) the spacing between the gain antennas is at least 50 ft. (15.24 m) (approximately the far field).

Pattern Distortions

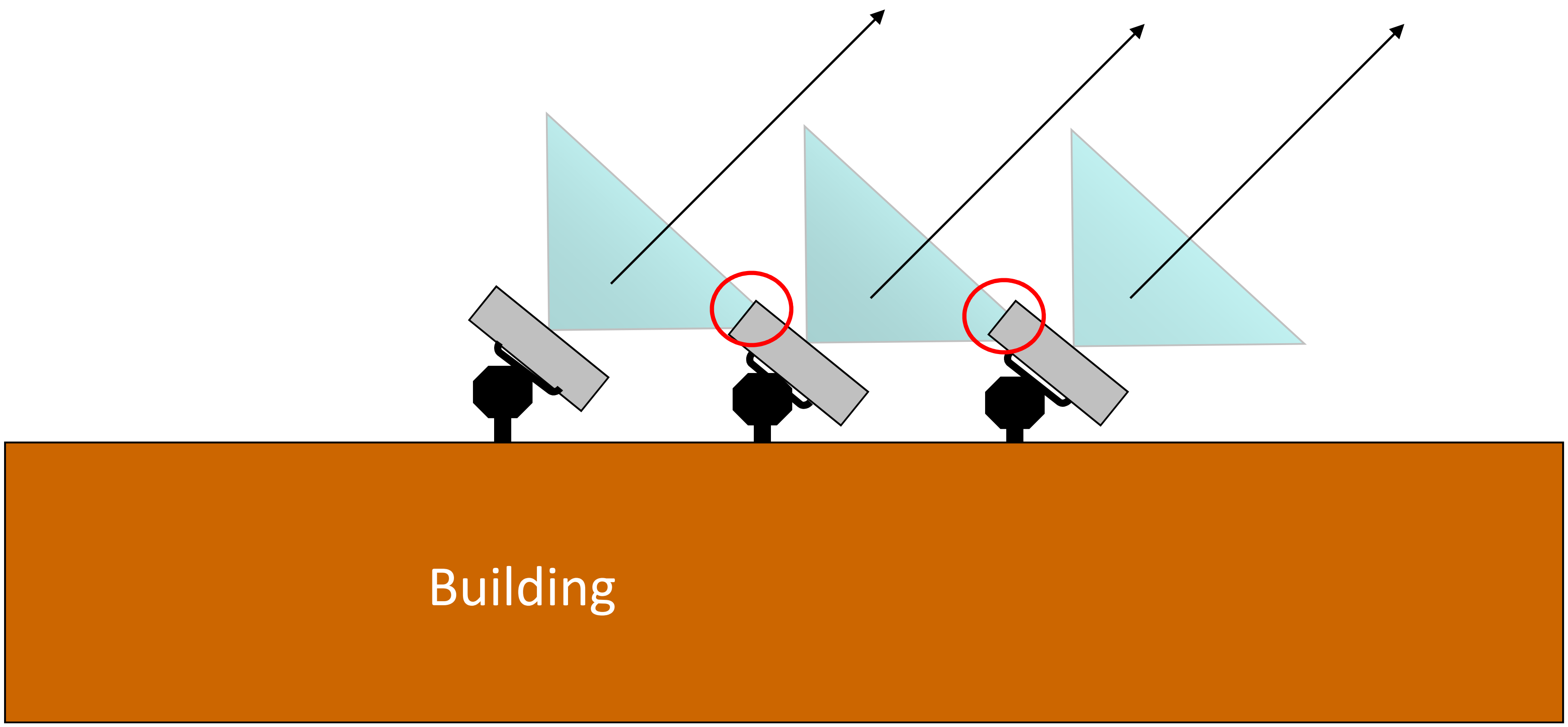
Conductive (metallic) obstruction in the path of transmit and/or receive antennas may distort antenna radiation patterns in a way that causes systems coverage problems and degradation of communications services.

A few basic precautions will prevent pattern distortions.

Additional information on metal obstructions can also be found online at:
www.akpce.com/page2/page2.html

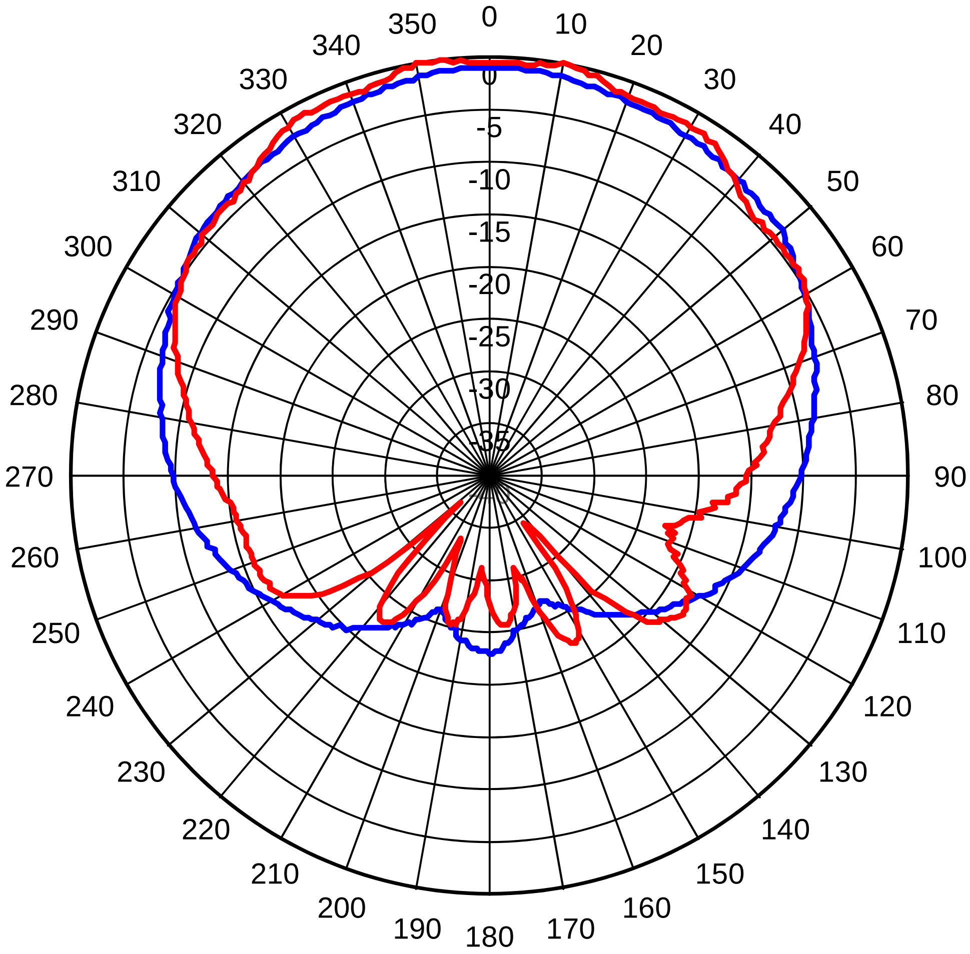
Pattern Distortions

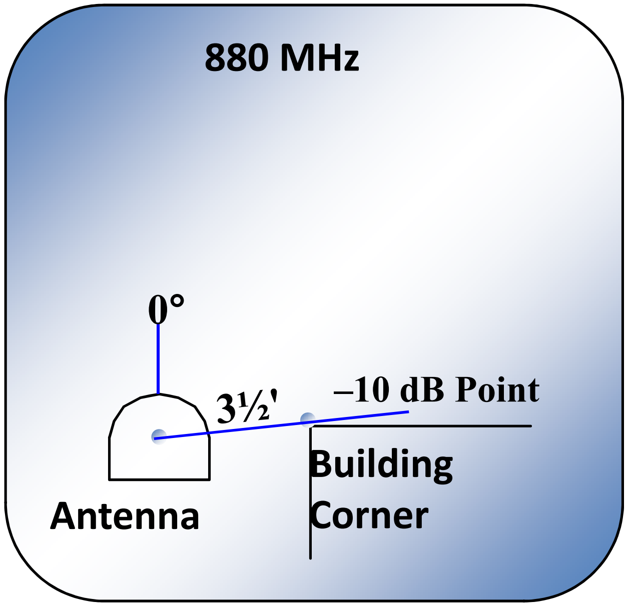
Side Of Building Mounting



90° Horizontal Pattern

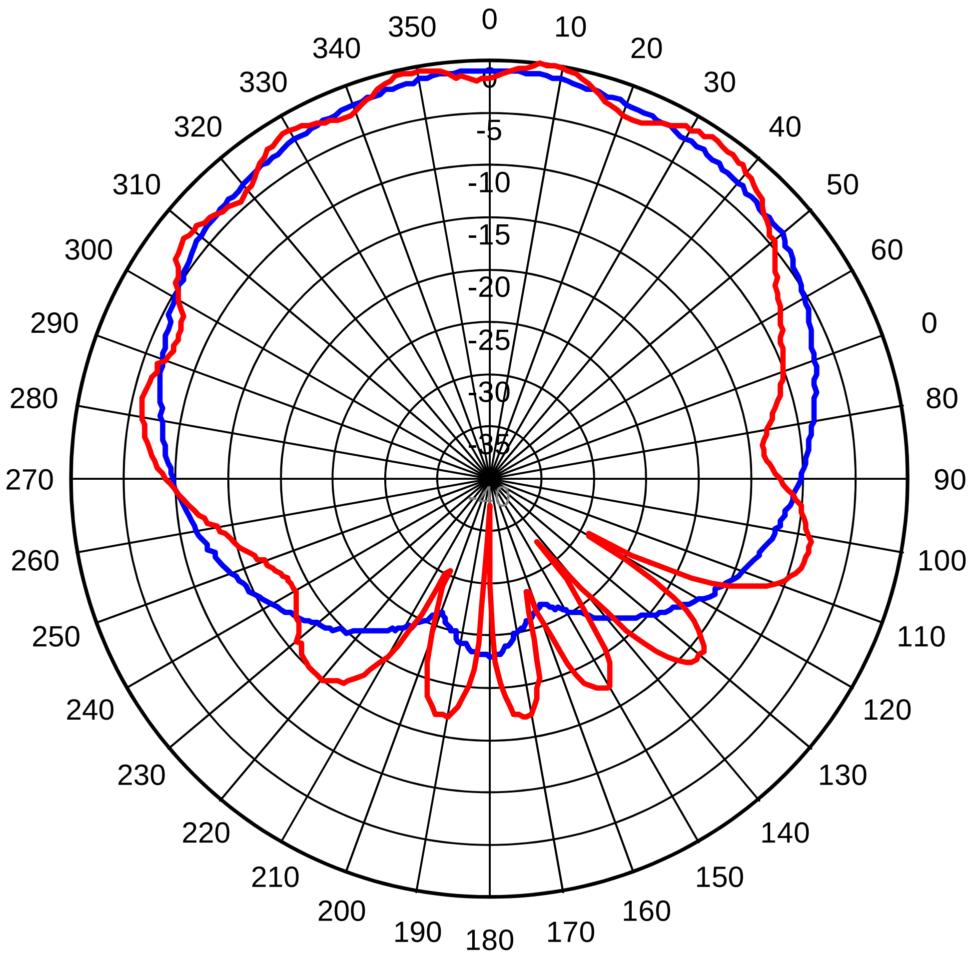
Obstruction @ –10 dB Point

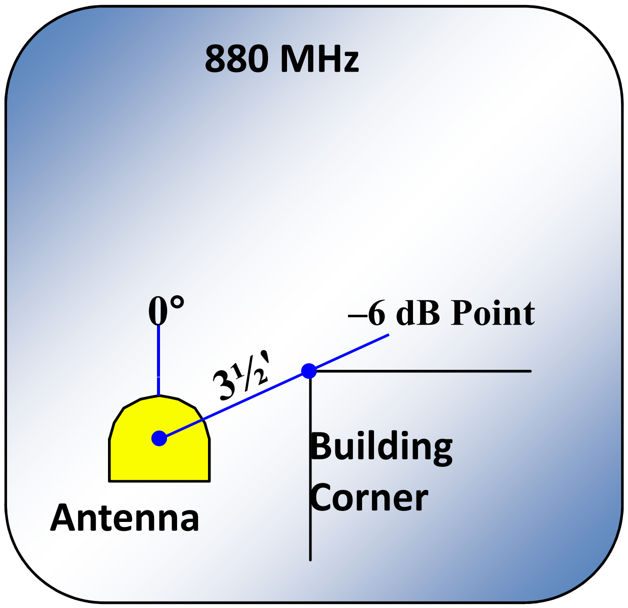




90° Horizontal Pattern

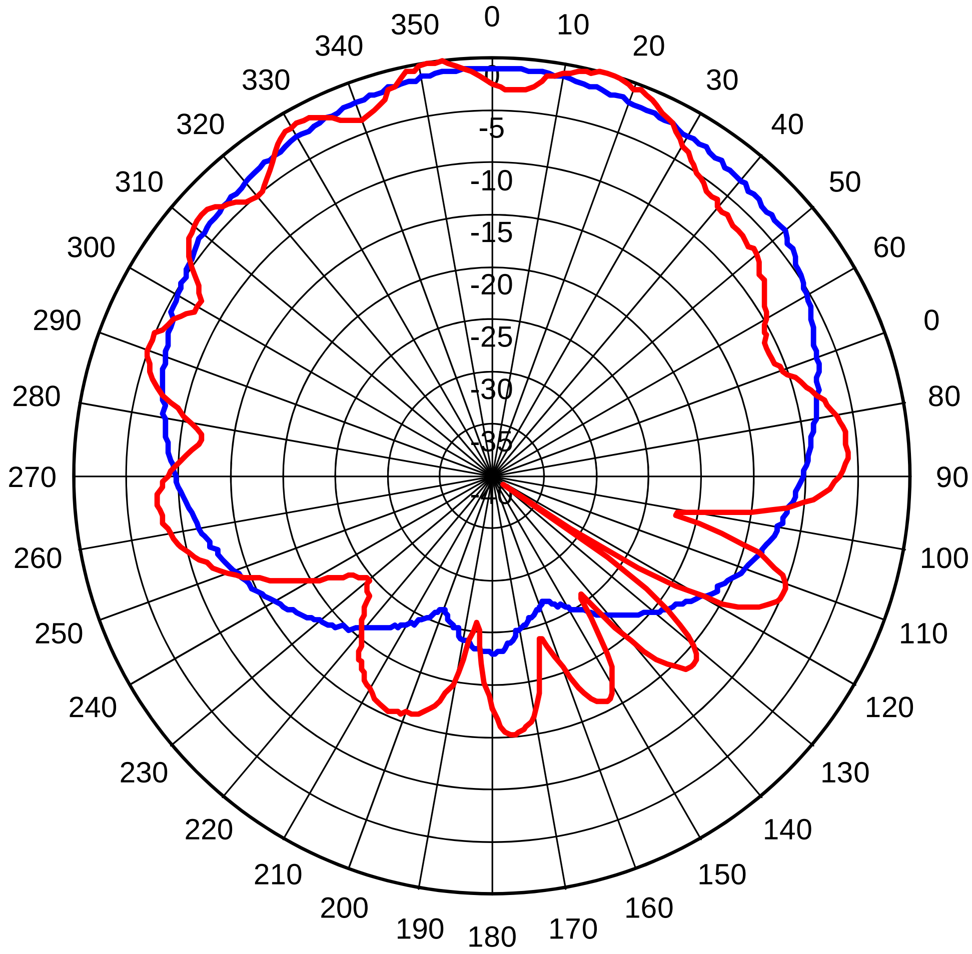
Obstruction @ –6 dB Point

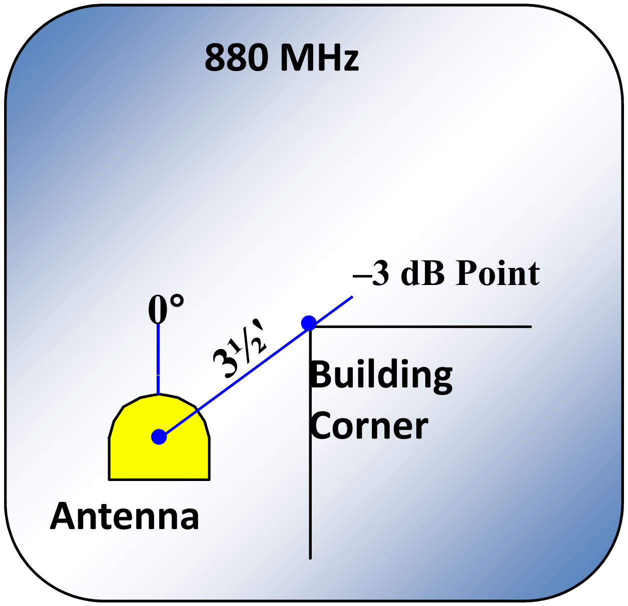




90° Horizontal Pattern

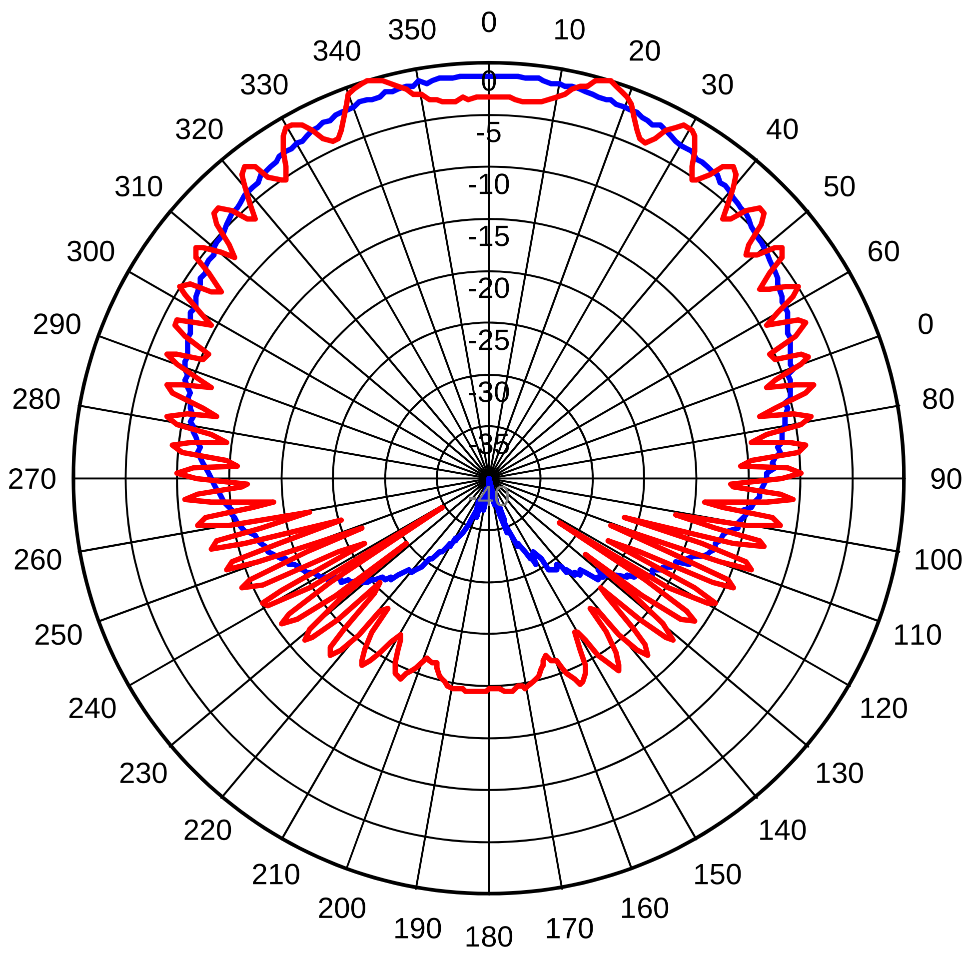
Obstruction @ –3 dB Point

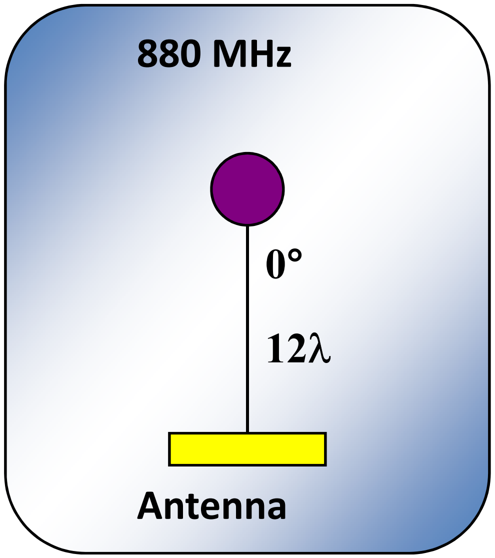




90° Horizontal Pattern

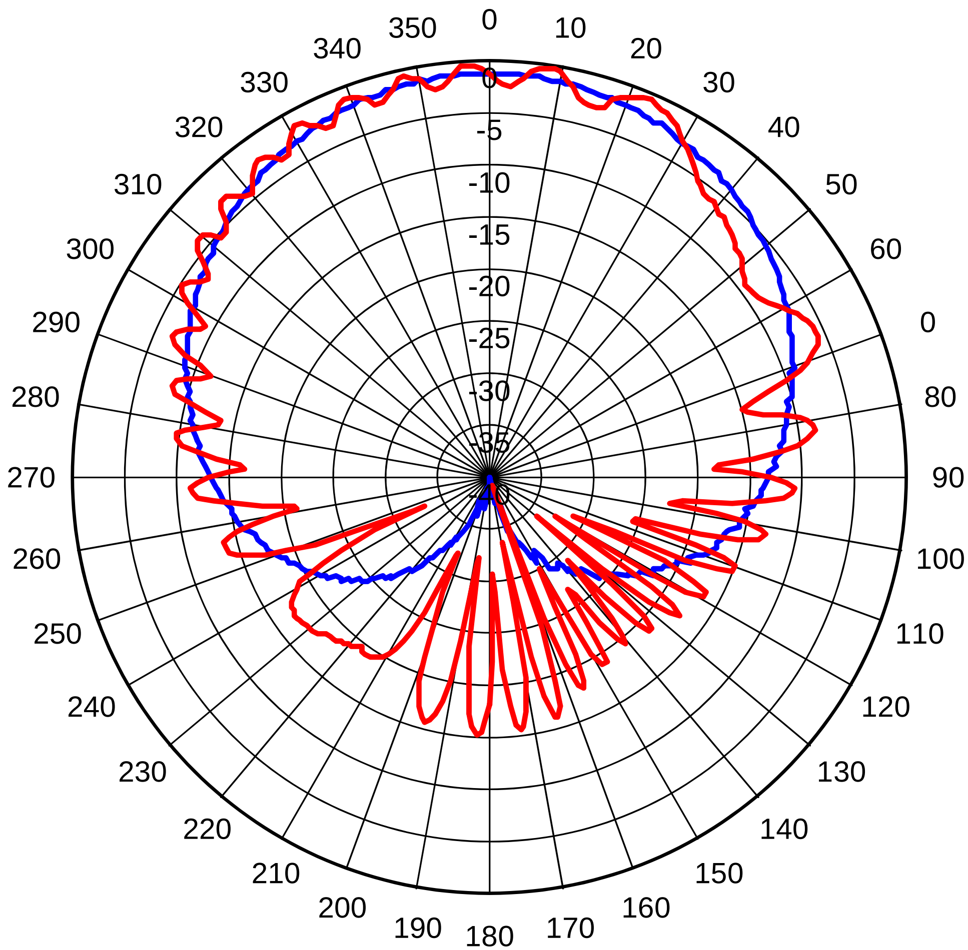
0.51λ Diameter Obstacle @ 0°

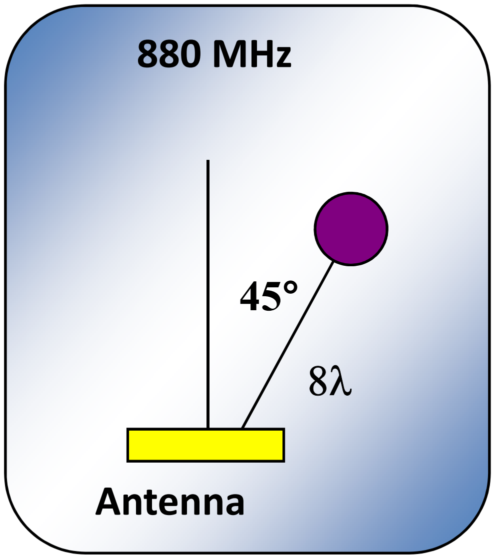




90° Horizontal Pattern

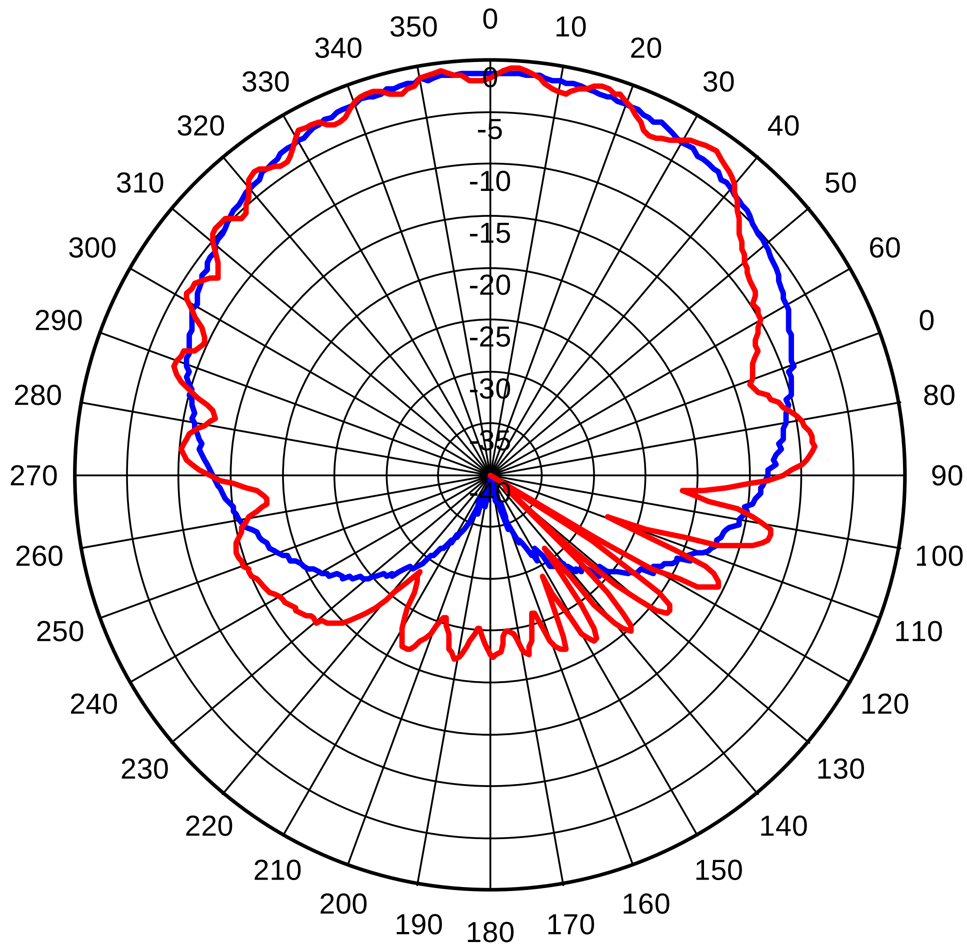
0.51λ Diameter Obstacle @ 45°

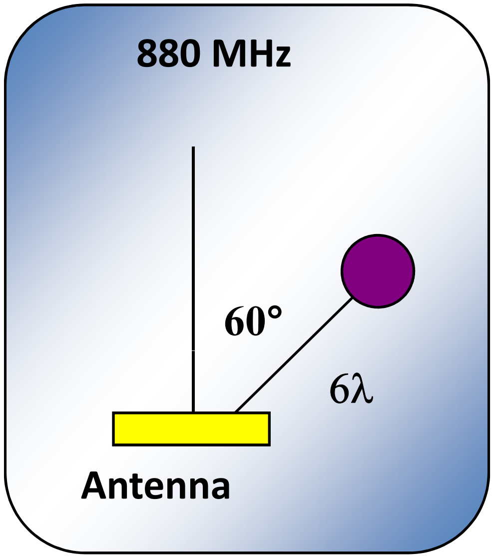




90° Horizontal Pattern

0.51λ Diameter Obstacle @ 60°

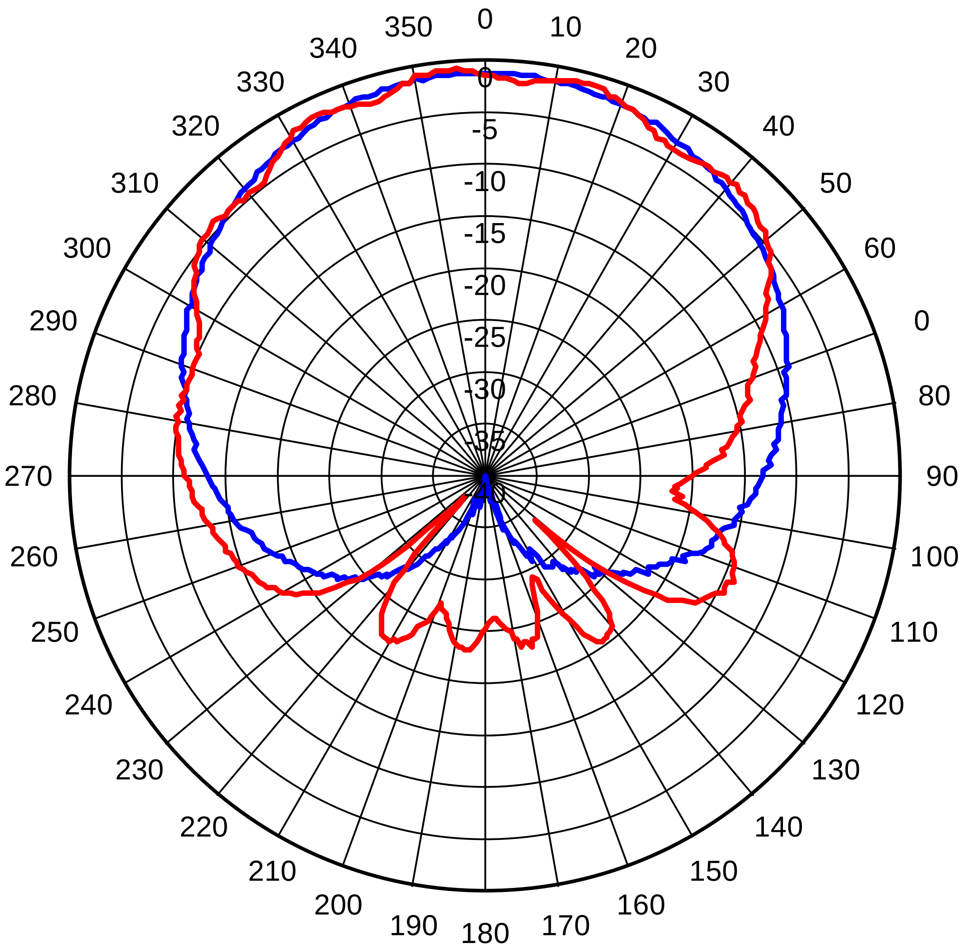


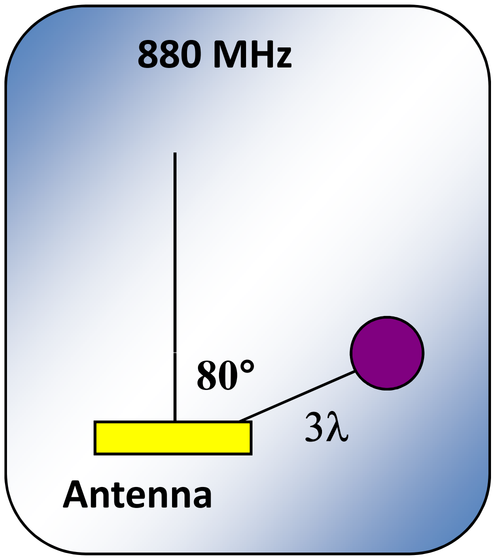


Additional information on metal obstructions can also be found online at www.akpce.com/page2/page2.html.

90° Horizontal Pattern

0.51λ Diameter Obstacle @ 80°

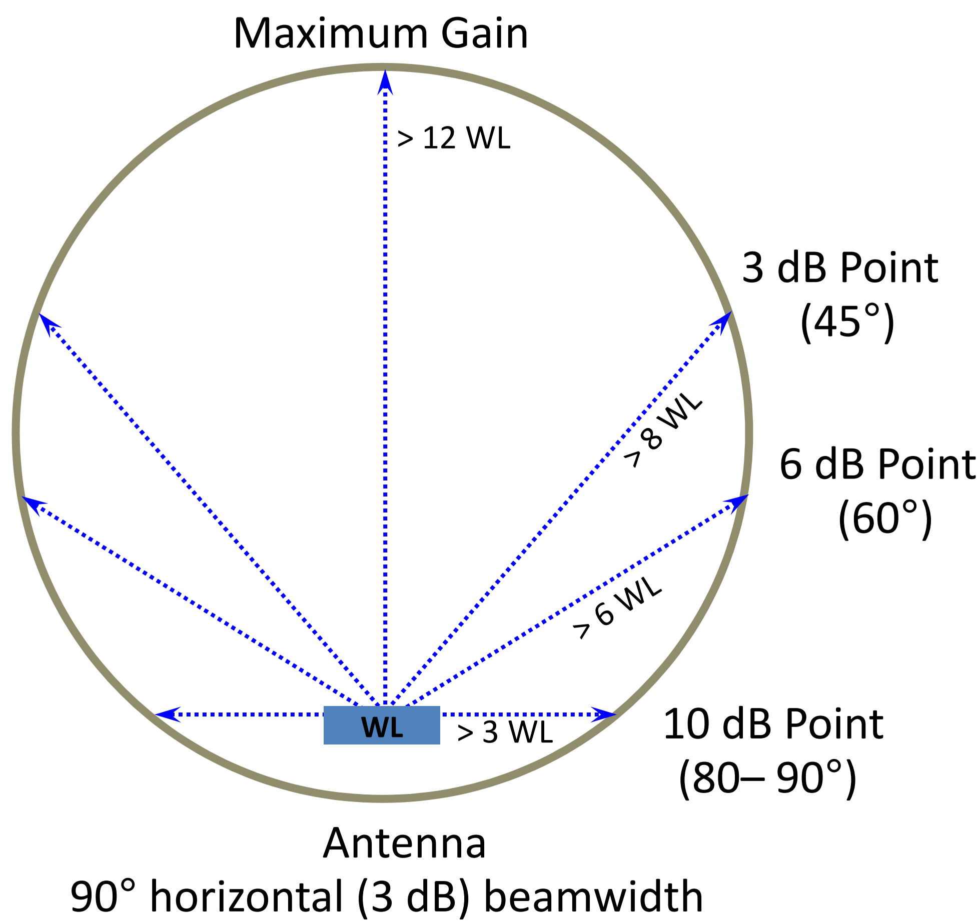




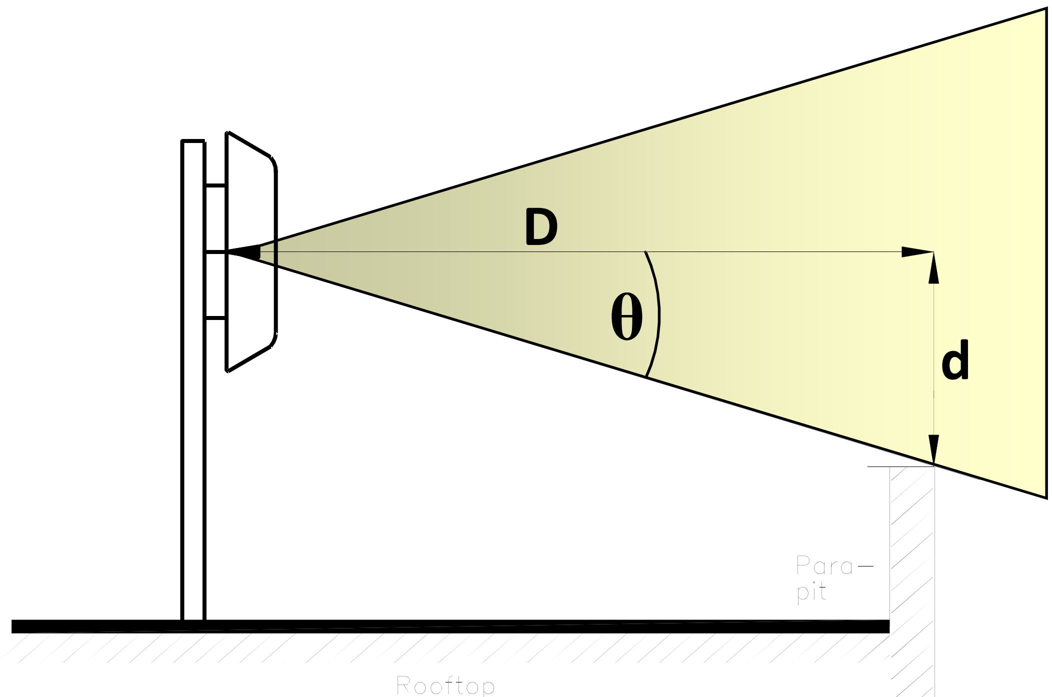
Additional information on metal obstructions can also be found online at www.akpce.com/page2/page2.html.

General Rule

Area That Needs To Be Free Of Obstructions (> 0.51λ)



Pattern Distortions



$$\tan\theta = \frac{d}{D}$$

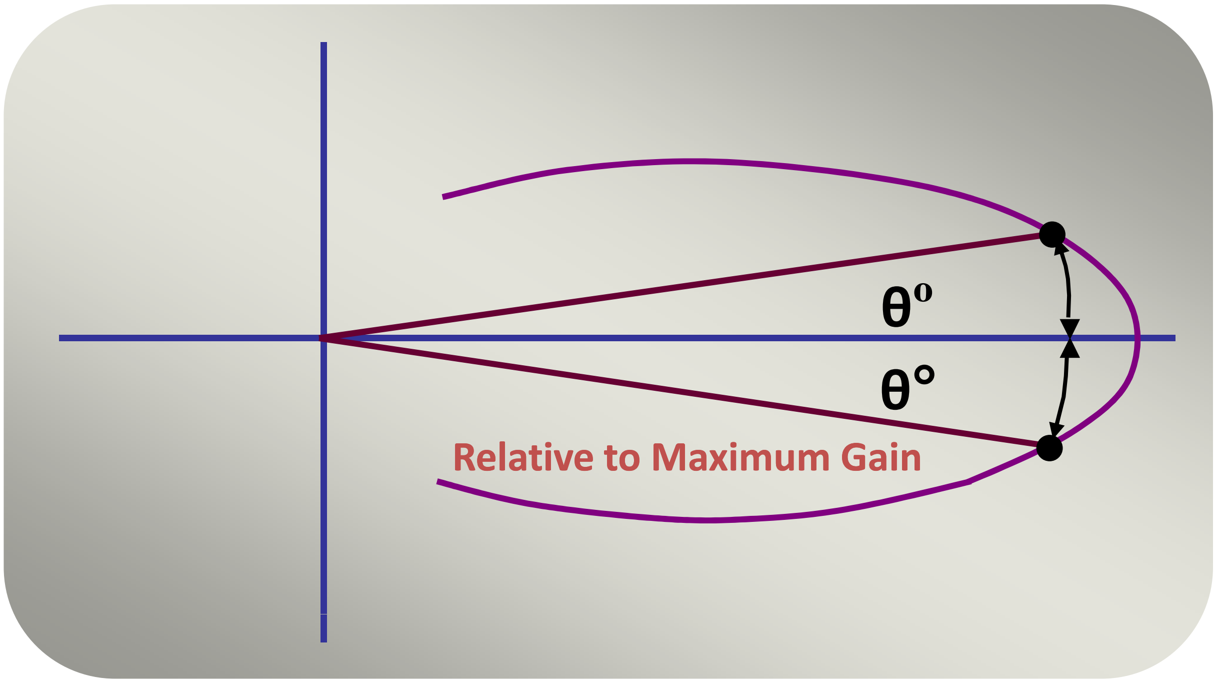
$$d = D \times \tan\theta$$

$$\tan 1° = 0.01745$$

$$\text{for } 0° < \theta < 10° \quad : \quad \tan\theta = \theta \times \tan 1°$$

Note: $\tan 10° = 0.1763$ $\qquad$ $10 \times 0.01745 = 0.1745$

Gain Points Of A Typical Main Lobe



Vertical Beam Width= 2 x θ° (–3 dB point)

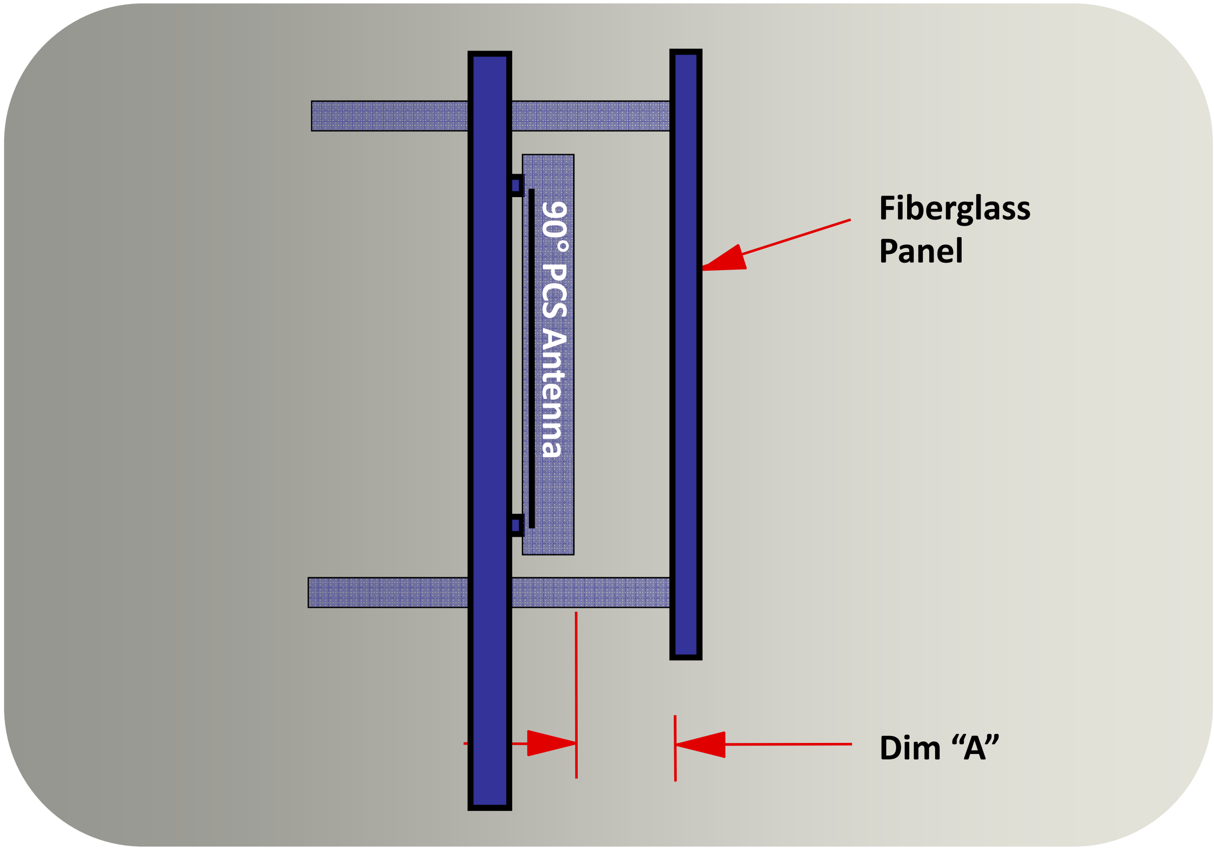
–3 dB point θ° below boresite.

–6 dB point 1.35 x θ° below boresite.

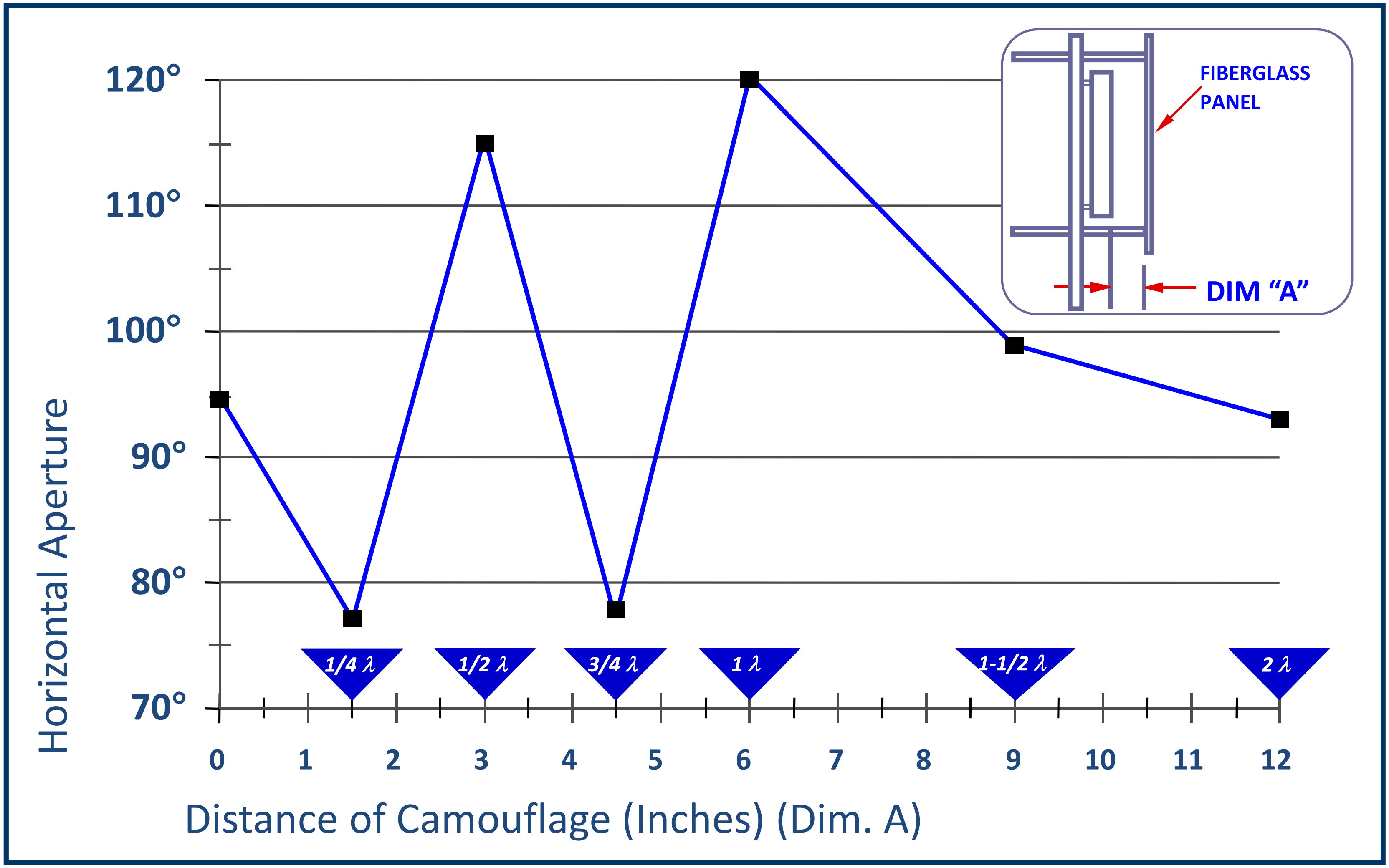
–10 dB point 1.7x θ° below boresite.

Changes In Antenna Performance
In The Presence Of:

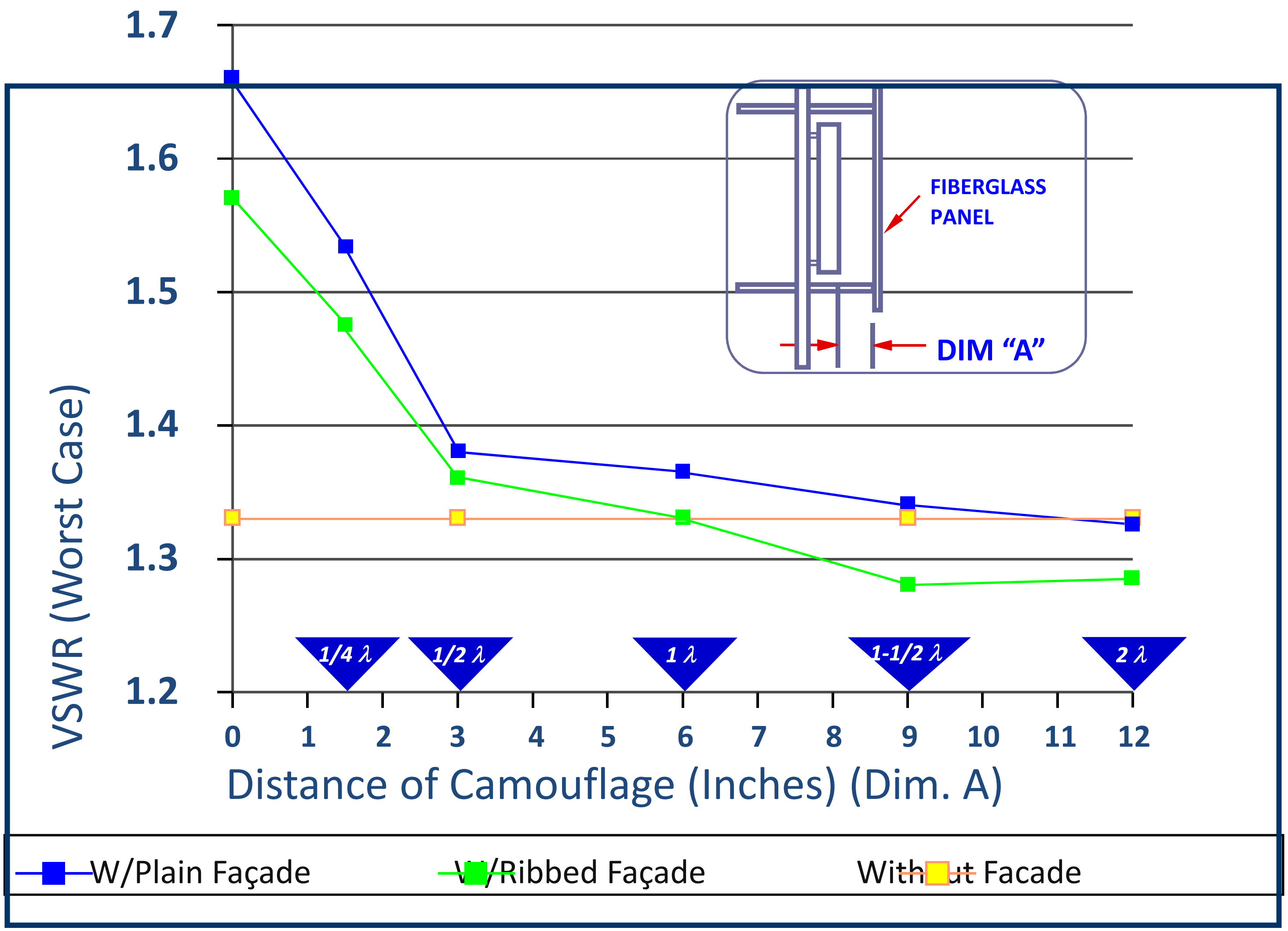
Non-Conductive Obstructions



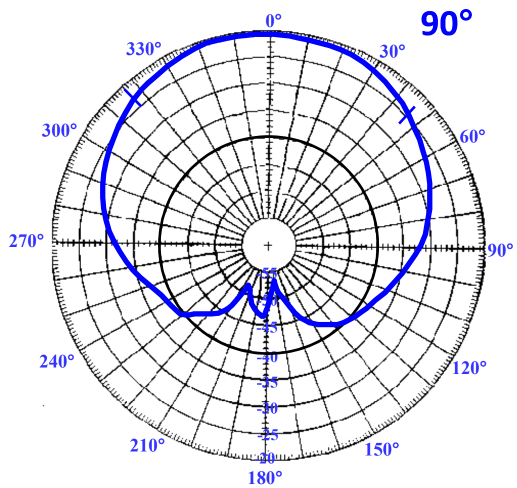
Performance Of 90° PCS Antenna Behind Camouflage (¼" Fiberglass)



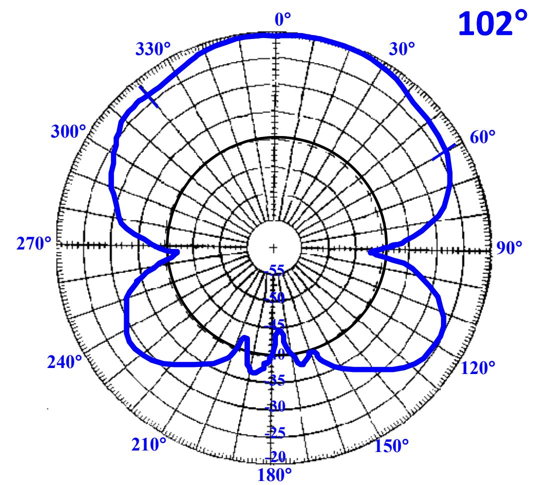
Performance Of 90° PCS Antenna Behind Camouflage (¼" Fiberglass)



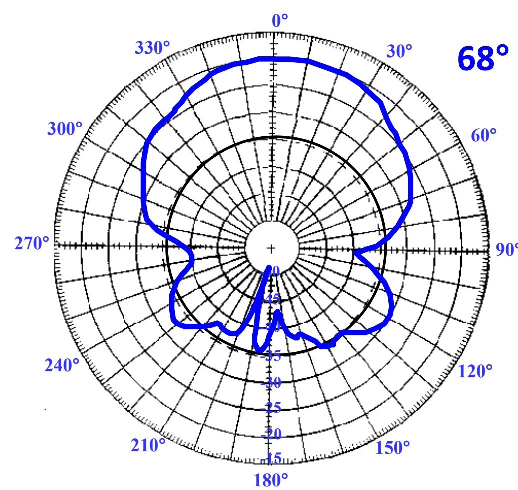
Distance From Fiberglass



No Fiberglass

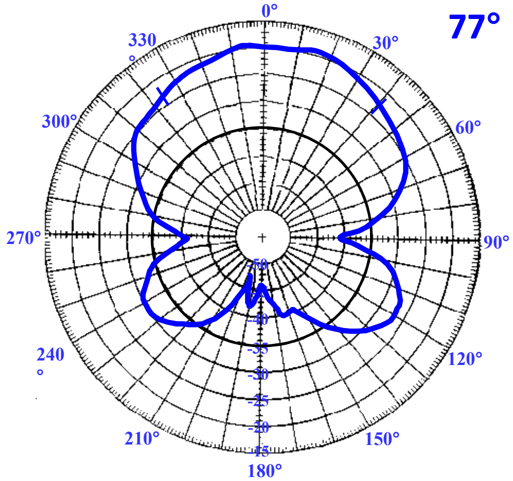


3" to Fiberglass

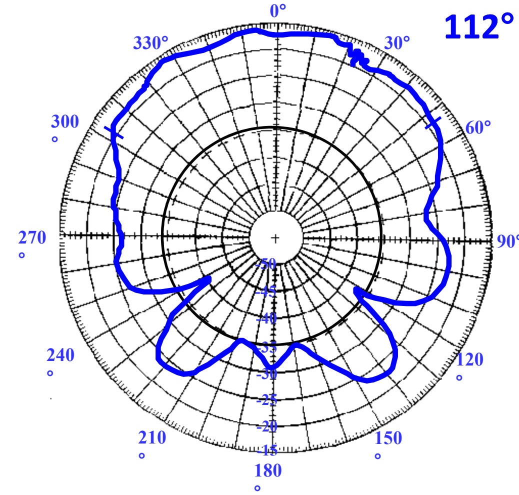


1.5" to Fiberglass

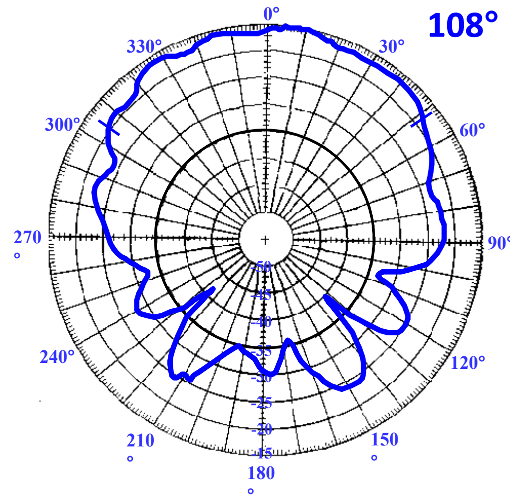
Distance From Fiberglass



4" to Fiberglass



6" to Fiberglass



9" to Fiberglass

ANTENNA AND RADAR ENGINEERING –ECE357

Text Books:

ANTENNA ENGINEERING

1. Antenna Engineering by John Kraus McGraw Hill 2009

2. Antenna Theory, Balanis C.A., John Wiley & Sons

3. Antenna and Radio Wave Propagation by Collins R.E. McGraw Hill

RADAR ENGINEERING

1. Microwave devices and Radar Engineering by M. Kulkarni, Umesh Publication

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- Antennas
- Fundamental Parameters of Antennas
- Arrays
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- Antennas
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ANTENNAS

- Introduction

- Types of Antenna

- Radiation Mechanism

  →Physical concept of Radiation in single wire, two wire

- Current Distribution on a Thin Wire Antenna

INTRODUCTION

- Antenna or Aerial :

  - is a transducer that transmits or receives electromagnetic waves

  - converts the voltage and current into the electromagnetic radiation and vice-versa

  - is a transitional structure between free-space and a guiding structure

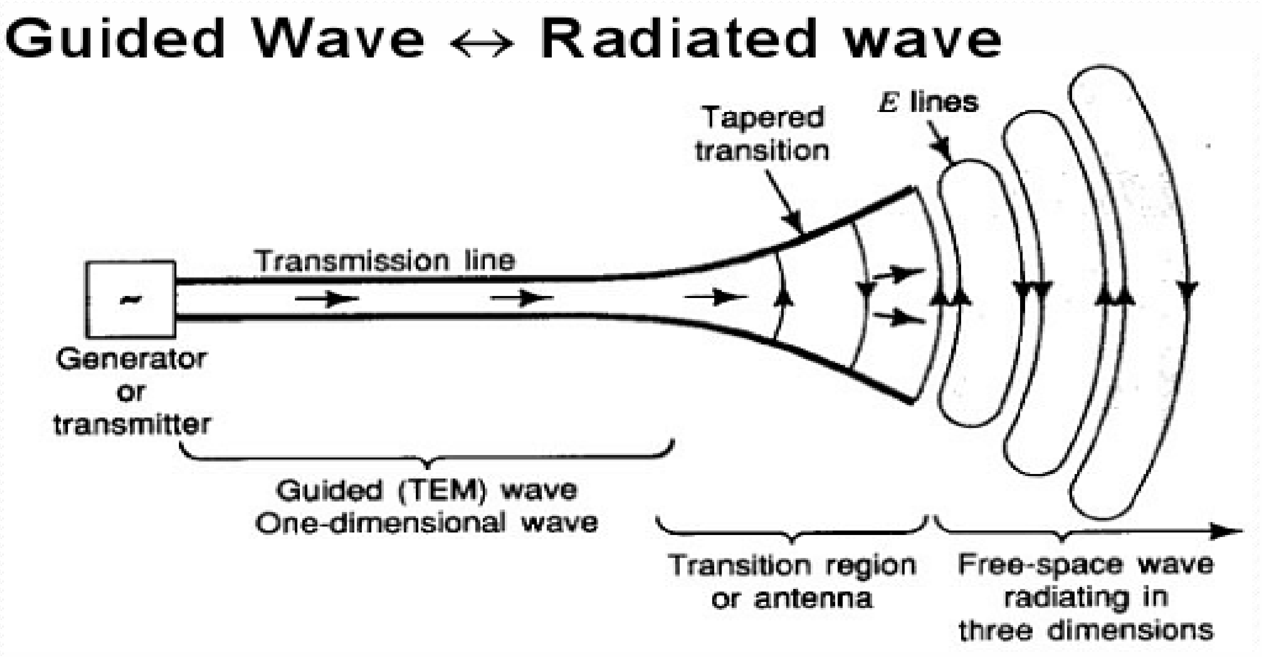
  - The American Heritage Dictionary: A metallic apparatus for sending and receiving electromagnetic waves.

  - Webster's Dictionary: A usually metallic device (as a rod or wire) for radiating or receiving radio waves

INTRODUCTION

- What is an Antenna?

An antenna is a device for radiating and receiving radio waves. The antenna is the transitional structure between free-space and a guiding device.



INTRODUCTION

- A transmission-line Thevenin equivalent of the antenna system

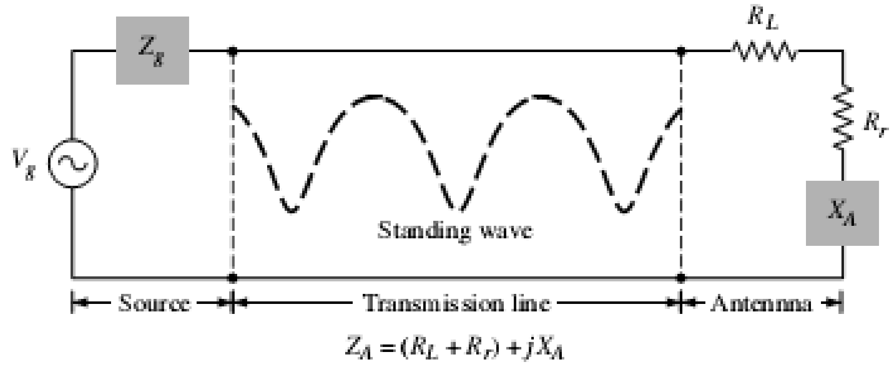
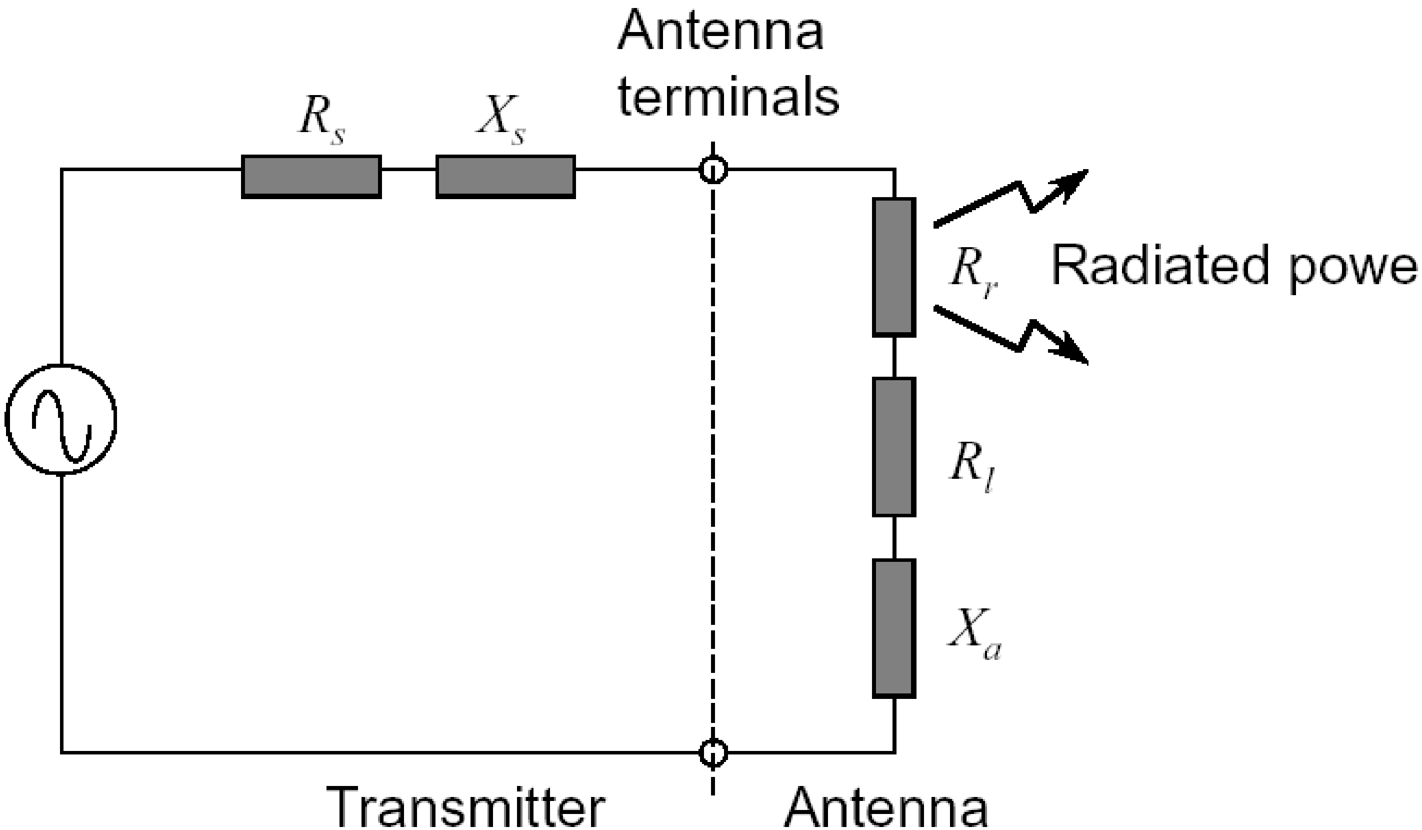


Figure 1.2 Transmission-line Thevenin equivalent of antenna in transmitting mode.

- The transmission line is represented by a line with characteristic impedance Z_c.
- The antenna is represented by a load $Z_A = (R_L + R_r) + jX_A$ connected to the transmission line.
- The load resistance R_L represents the conduction and dielectric losses associated with the antenna structure.
- R_r, the radiation resistance, represents radiation by the antenna.
- The reactance X_A represents the imaginary part of the impedance associated with radiation by the antenna.

Radiation Resistance & Efficiency



$$e = \frac{\text{Power radiated}}{\text{Power accepted by antenna}} = \frac{R_r}{R_r + R_l}$$

INTRODUCTION

- A transmission-line Thevenin equivalent of the antenna system

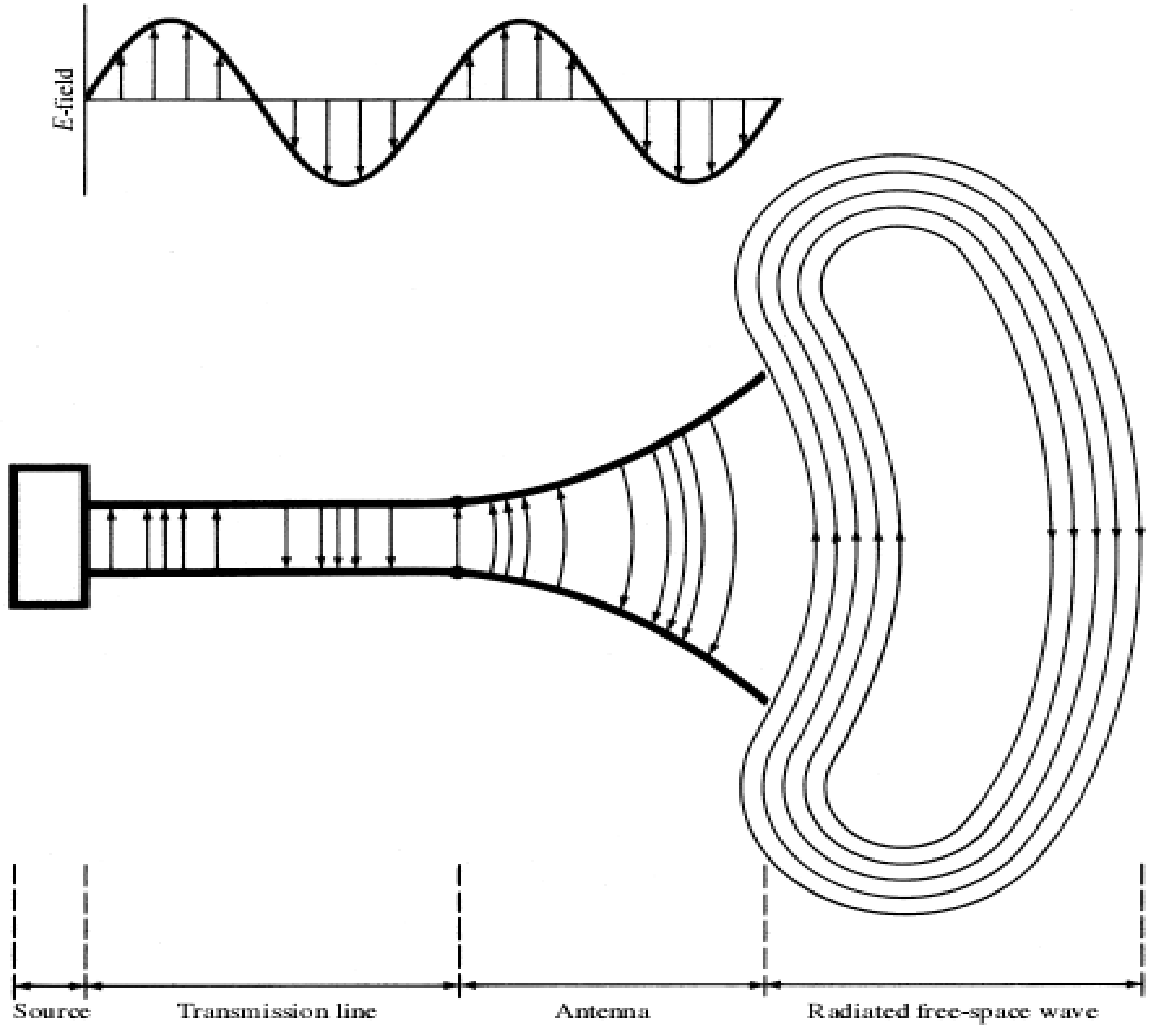
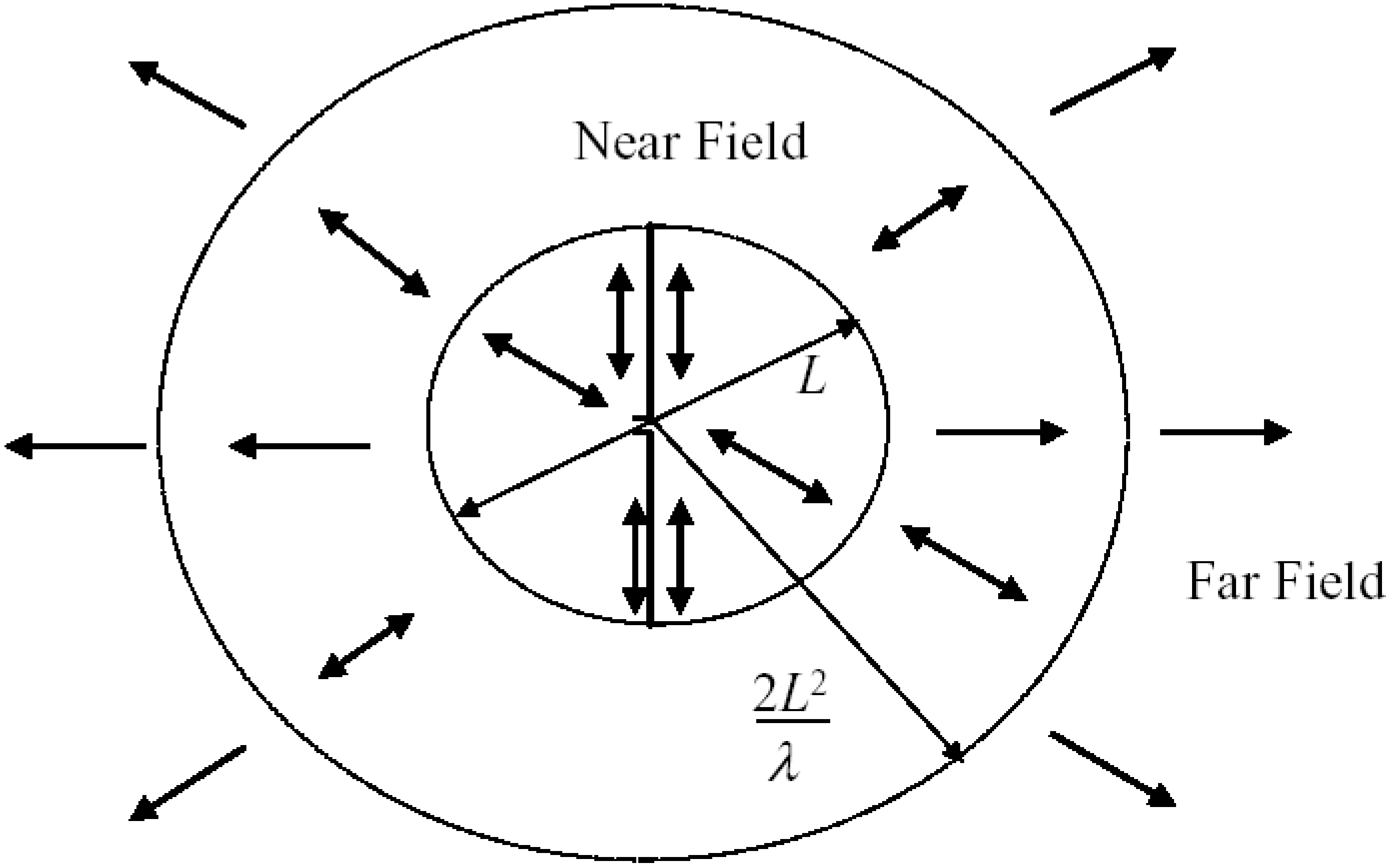


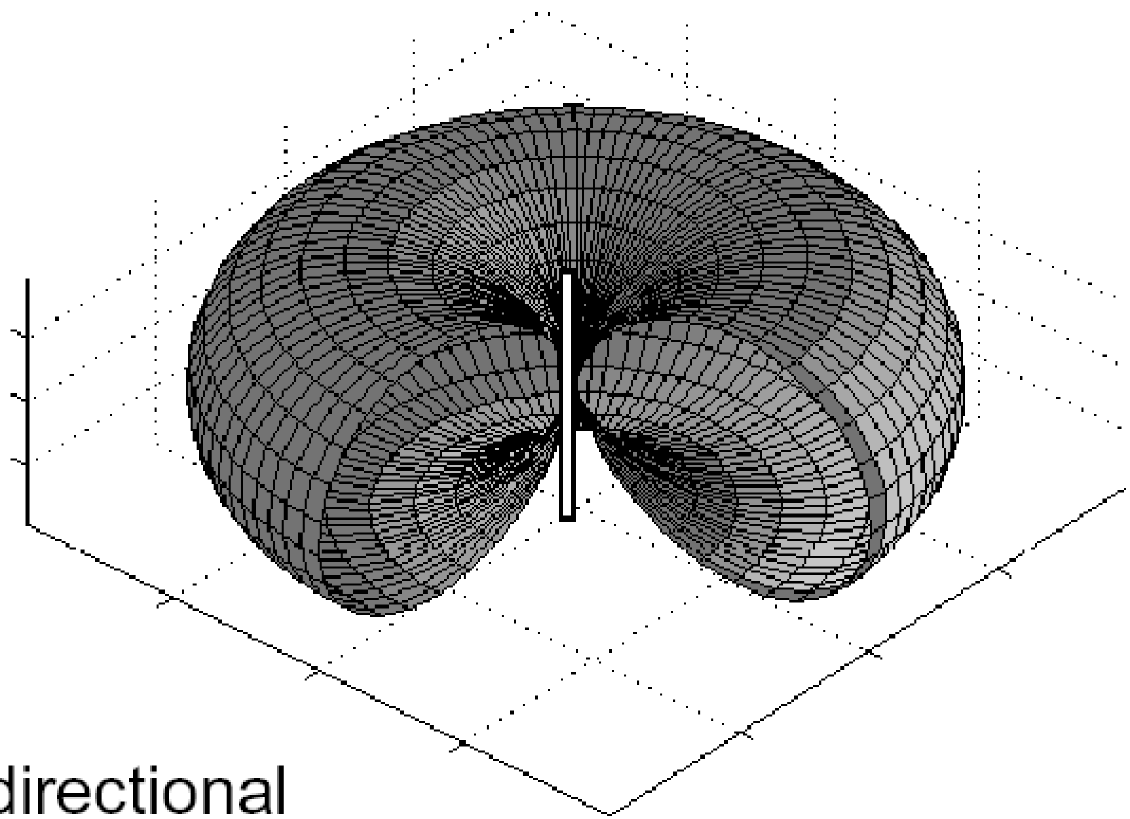
Figure 1.1 Antenna as a transition device.

Field Regions

- Near / Fresnel Region - Reactive Fields
- Far / Fraunhofer region - Real Fields



Radiation Pattern for Hertzian Dipole



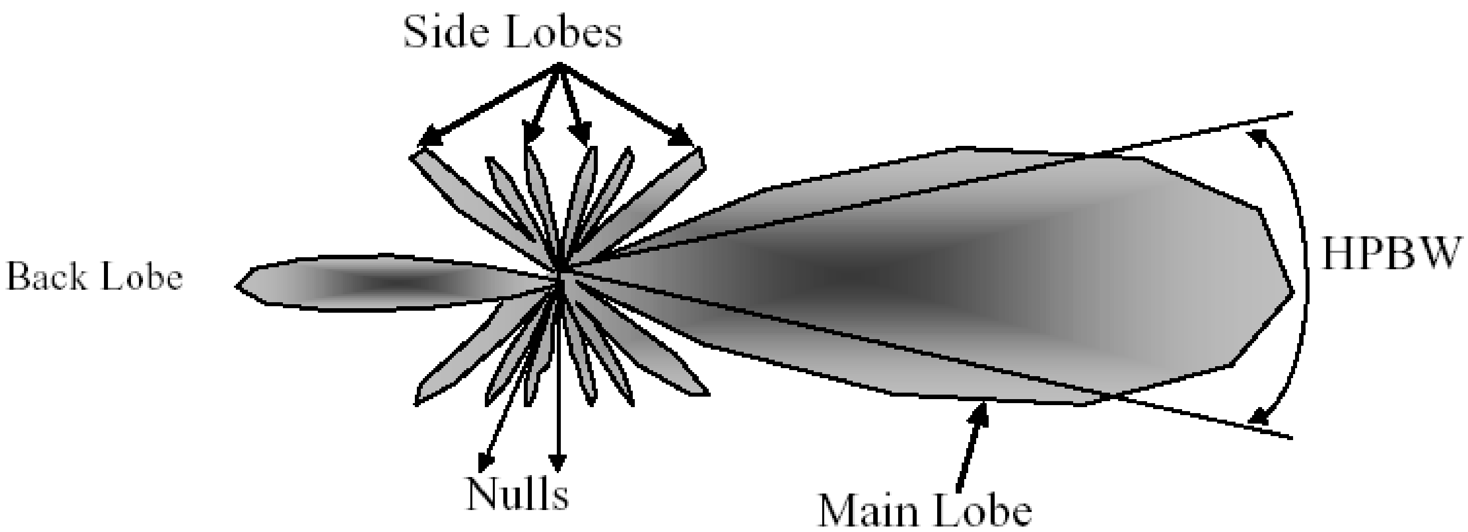
Omnidirectional

Radiation Pattern

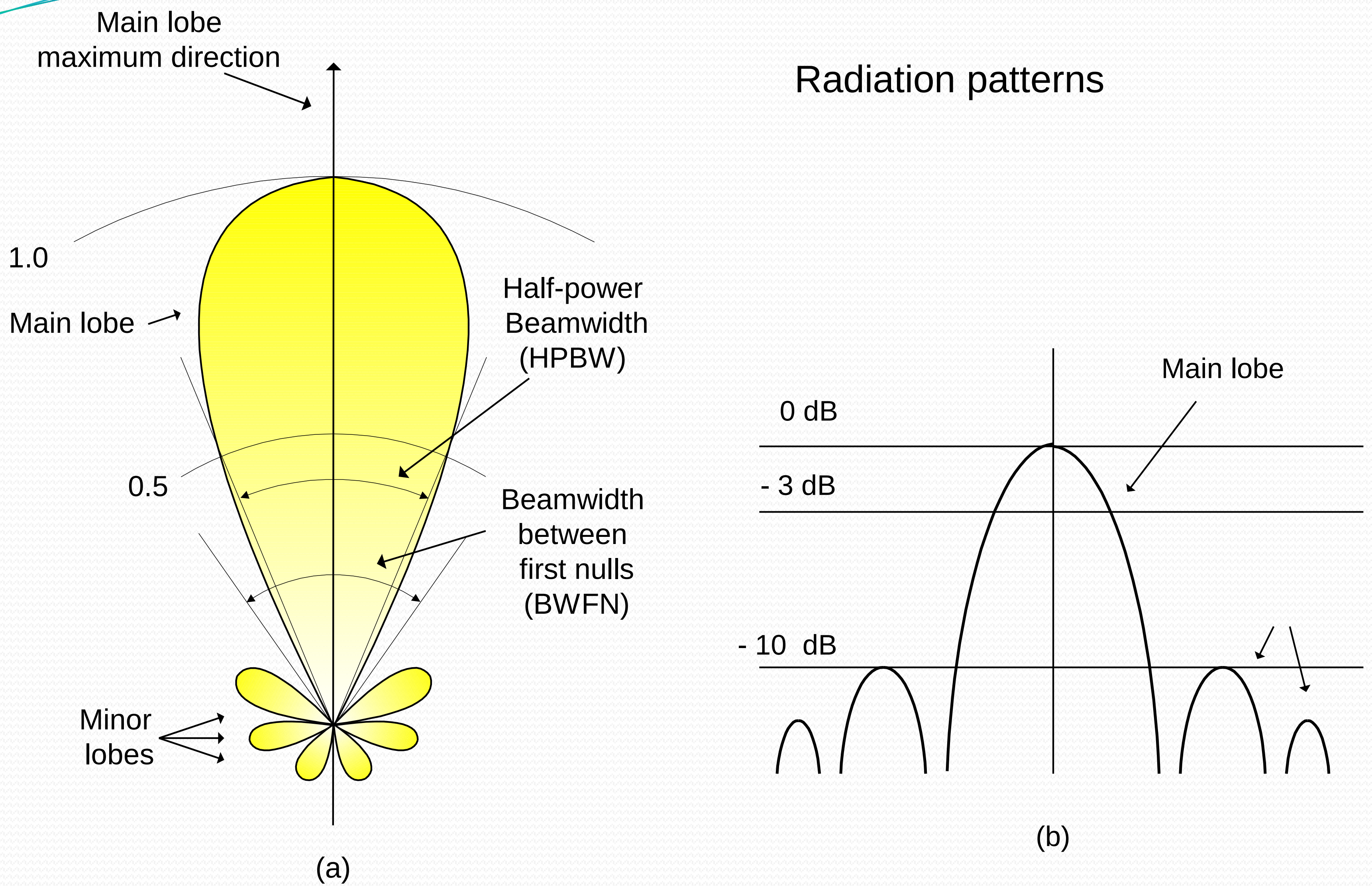
- Magnitude of Poynting vector, multiplied by r^2

Features:

- Lobes
- Half Power beamwidth
- Side-lobe Level
- Isotropic & Omnidirectional



Radiation patterns



Isotropic Radiation Pattern

- Characteristics
  - Completely non-directional antenna
  - Radiates and receives equally well in all directions
  - Radiation pattern is spherical

- Exists only as a mathematical concept

- Used as a reference

Antenna Polarization

- Polarization is an important property of EM Waves
- Orientation of E-field determines polarization
  - If electrical field is vertical, radio wave is polarized vertically
  - If electrical field is horizontal, radio wave is polarized horizontally
- Antenna of receiver should be oriented in same direction as polarization of transmitted field

INTRODUCTION

Maximum Power Transfer

Losses in practical systems:

- Conduction-dielectric losses due to the lossy nature of the transmission line and the antenna.
- Losses due to reflections (mismatch) losses at the interface between the line and the antenna.

If we neglect mismatch, maximum power is delivered to the antenna under conjugate matching.

Standing Waves

- Due to the interference between the forward wave and the reflected wave, *standing waves* are created: energy pockets.
- This makes the transmission line an energy storage device than a wave guiding and energy transport device.
- If the maximum field intensities of the standing wave are sufficiently large, they can cause arching inside the transmission lines.

INTRODUCTION

Reducing Losses

The losses due to the line, antenna, and the standing waves are undesirable.

- Line: select a low loss line.
- Antenna: reduce the loss resistance R_L.
- Standing waves: match the impedance of the antenna (load) to the characteristic impedance of the line.

Antennas

- Introduction
- Types of Antenna
- Radiation Mechanism
  - →Physical concept of Radiation in single wire, two wire
- Current Distribution on a Thin Wire Antenna

TYPES OF ANTENNAS

- Wire antennas
- Aperture antennas
- Microstrip antennas
- Array antennas
- Reflector antennas
- Lens antennas

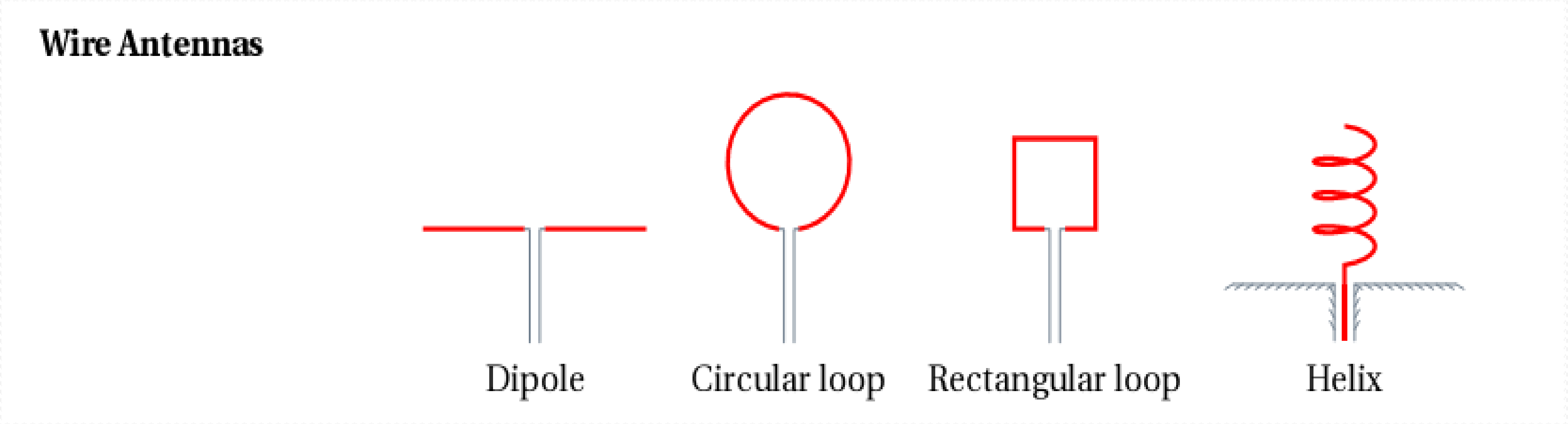
Wire antennas

→ seen virtually everywhere- on automobile, building, ships, aircraft, and so on.

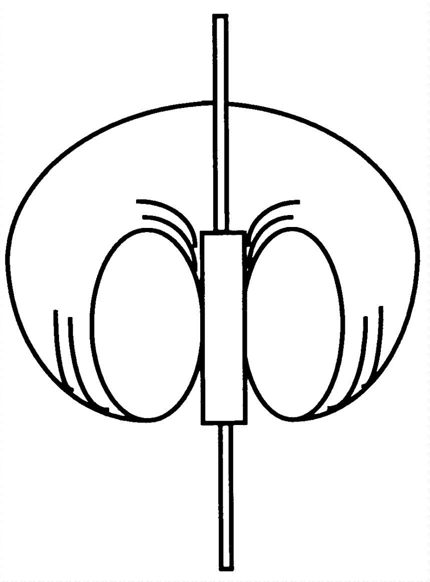
- Shapes of wire antennas:

  straight wire (dipole), loop (circular), and helix,

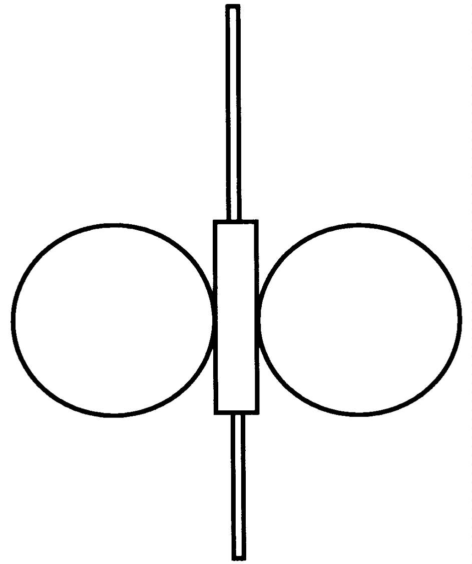
  Loop antenna may take the shape of a rectangle , ellipse or any other shape configuration



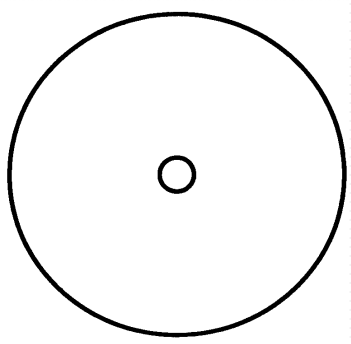
Radiation Pattern of Half-wave Dipole Antenna



3-D view

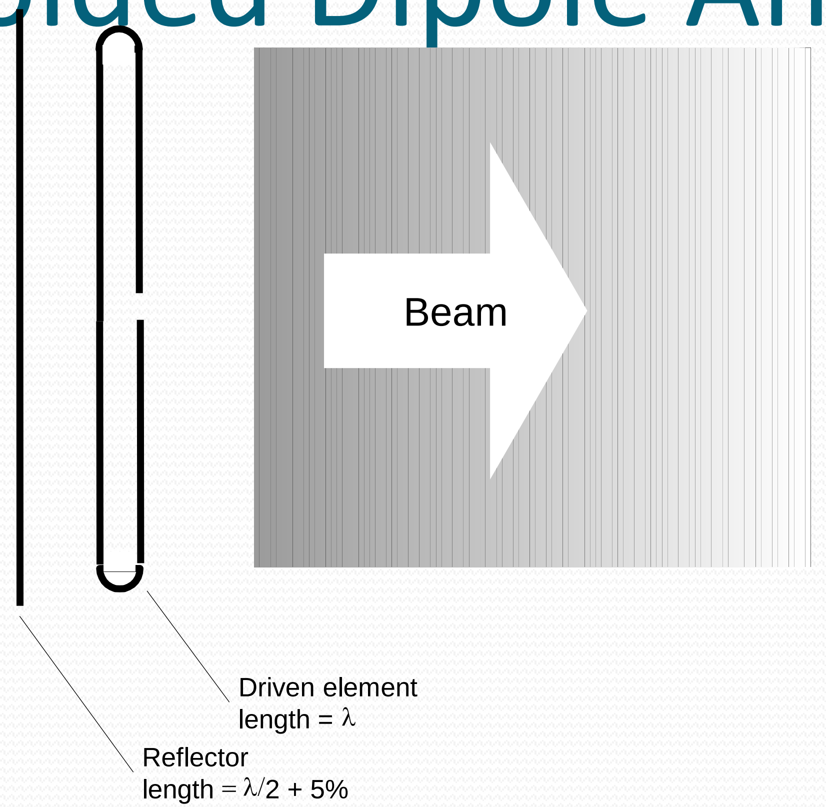


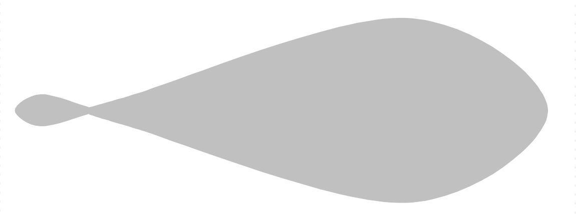
Vertical section



Horizontal section

Folded Dipole Antenna

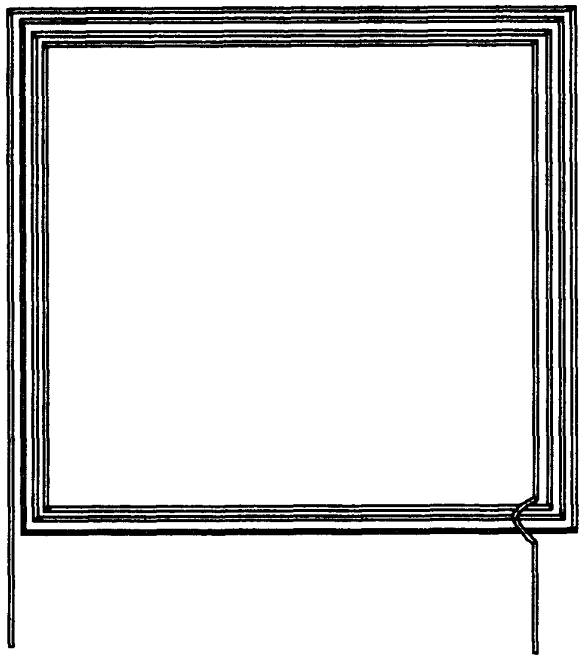




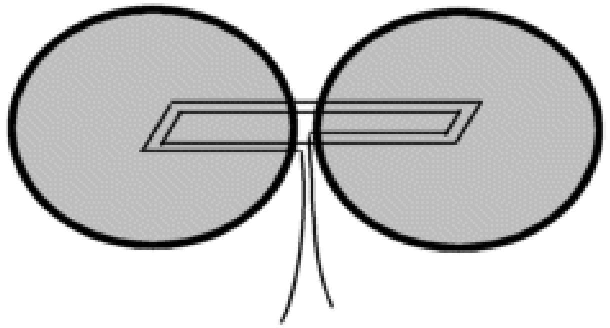
Folded dipole antenna

Radiation pattern

Loop Antenna



Loop antenna



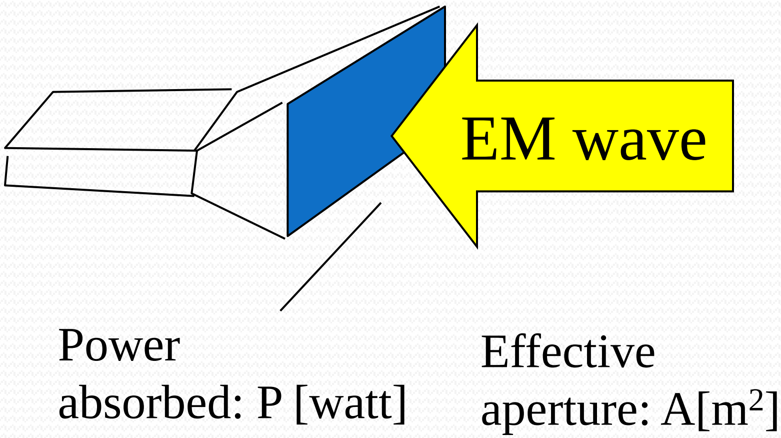
Radiation pattern in horizontal plane

Aperture-antenna

- Aperture antennas derived from waveguide technology (circular, rectangular)

- Can transfer high power (magnetrons, klystrons)

→Utilization of higher frequencies



Applications: aircraft, and spacecraft

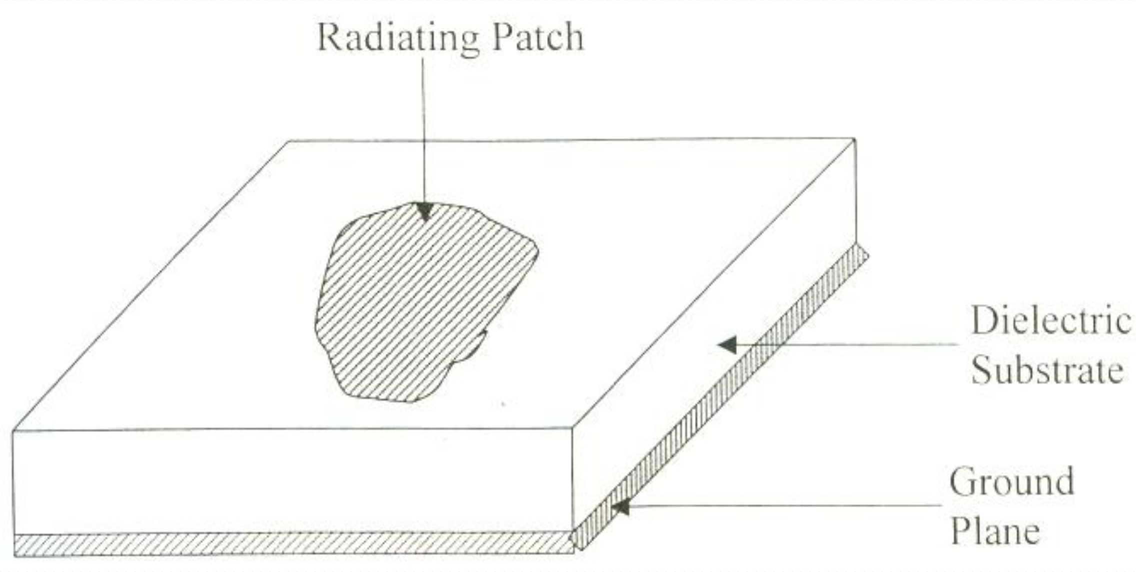
Note: The aperture concept is applicable also to wired antennas.
For instance, the max effective aperture of linear $\lambda/2$ wavelength dipole antenna is $\lambda^2/8$

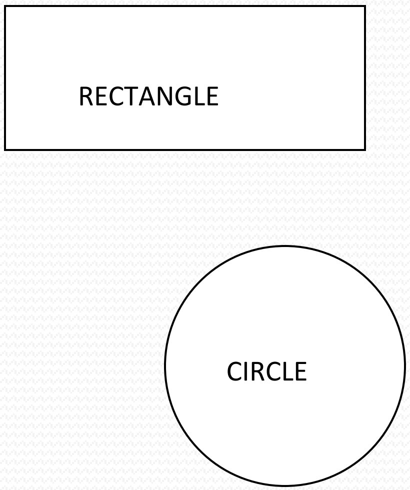
Microstrip antenna

→consist of metallic patch on a grounded substrate

Examples: rectangular and circular shape

Applications: aircraft, spacecraft, satellite, missiles, cars etc



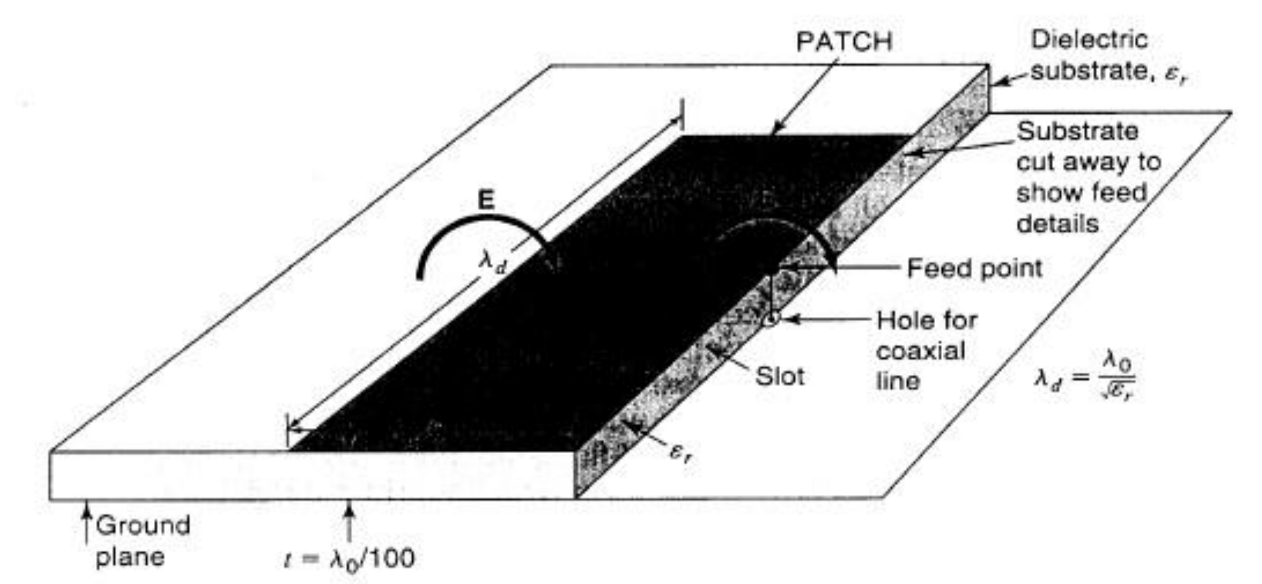


Patch Antennas

- Radiation is from two “slots” on left and right edges of patch where slot is region between patch and ground plane
- Length $\lambda_d = \lambda_o/\varepsilon_r^{1/2}$ Thickness typically ≈ 0.01 λ_o

The big advantage is conformal, i.e. flat, shape and low weight

Disadvantages: Low gain, Narrow bandwidth (overcome by fancy shapes and other heroic efforts), Becomes hard to feed when complex, e.g. for wide band operation



Patch Antenna Pattern

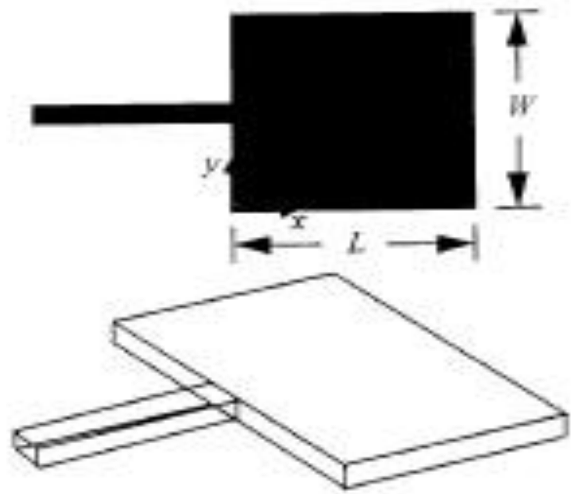


FIGURE 21.11. Half-wave patch antenna (conductor pattern and perspective view)

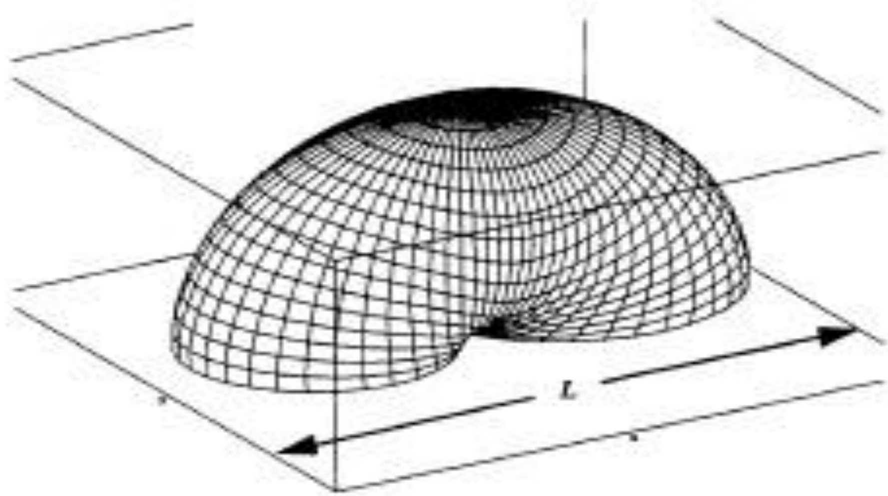
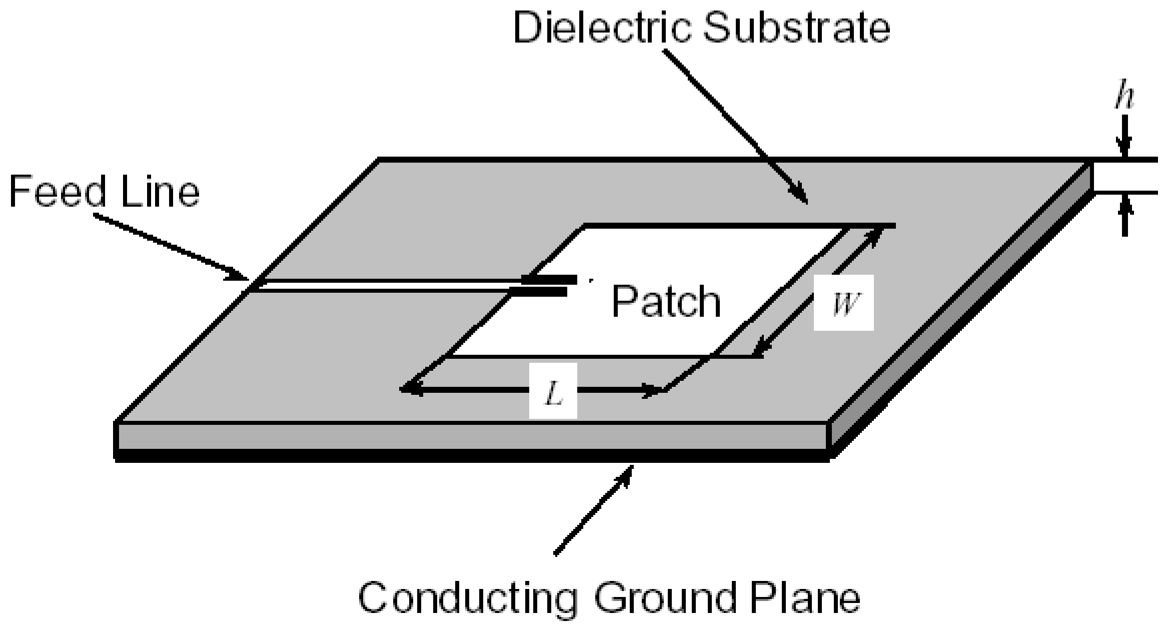


FIGURE 21.12. Typical radiation pattern for patch antenna of Figure 21.11

The Patch Antenna

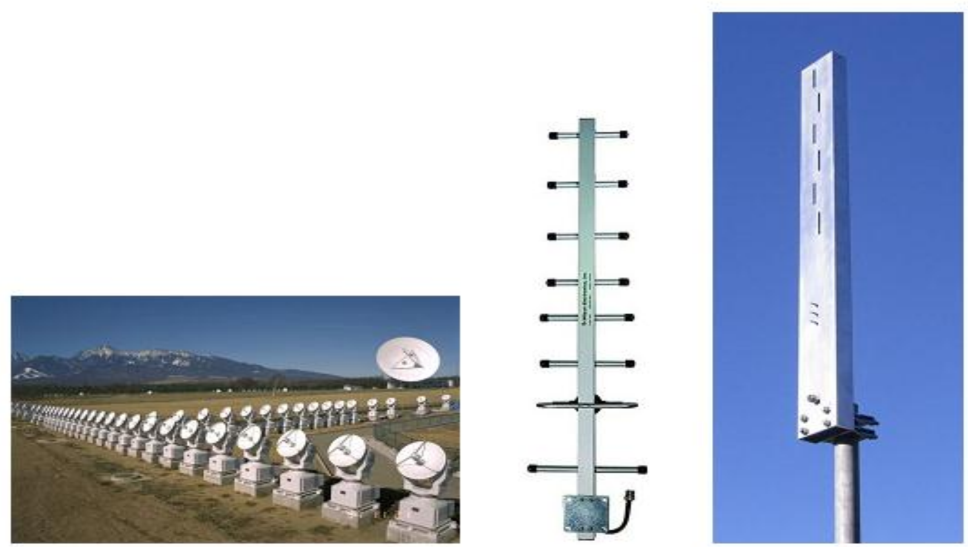


Array antennas

“a collection of simple antennas”

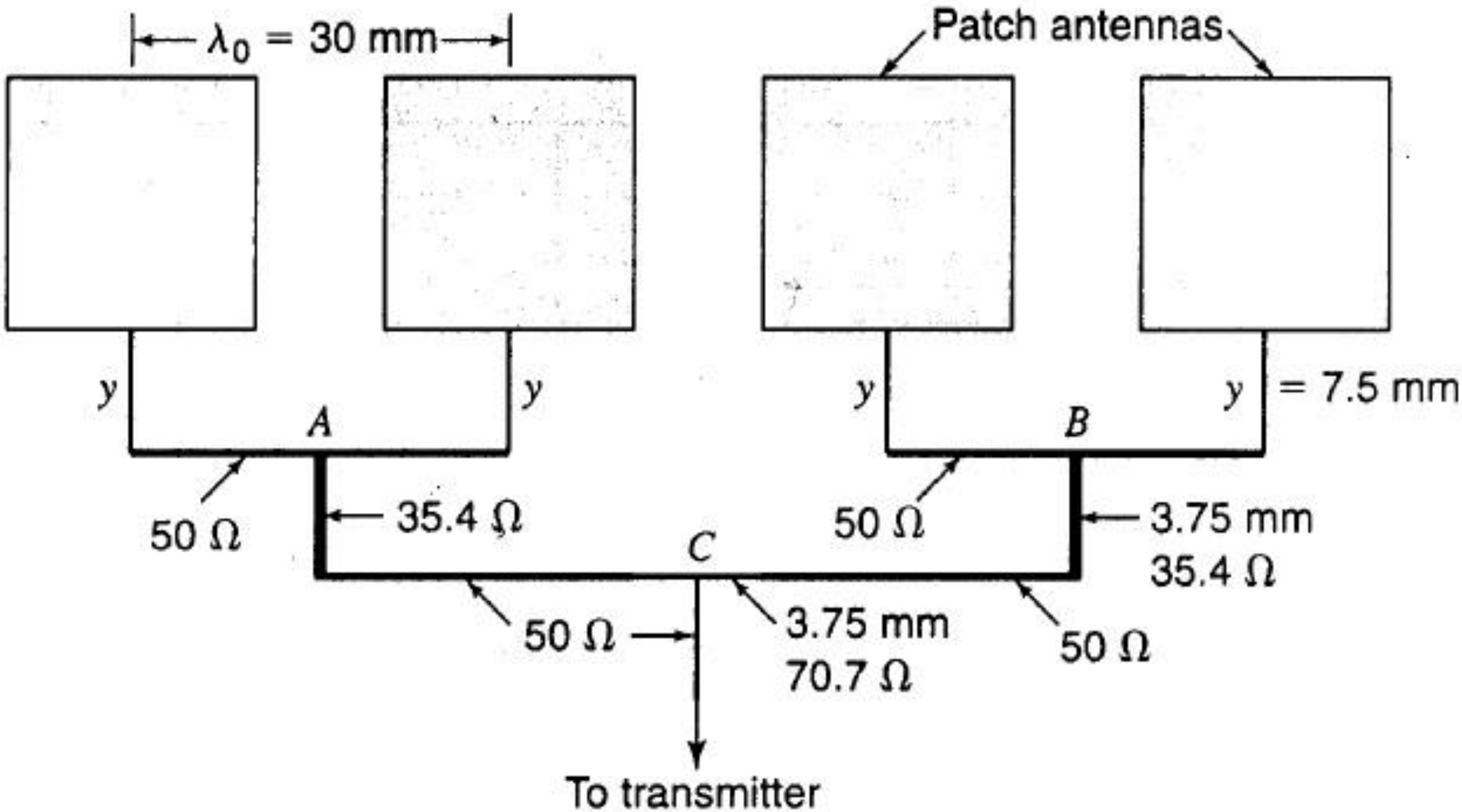
- gives desire d radiation characteristics
- The arrangement of the array may be such that the radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others, or otherwise as desired
- **Examples:** yagi-uda array, aperture array, microstrip patch array, slotted waveguide array

Antennas Arrays



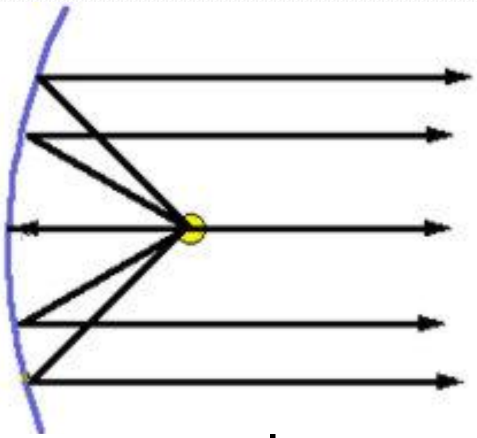
Reflector array [8] Yagi Uda [2] Slotted waveguide [3]

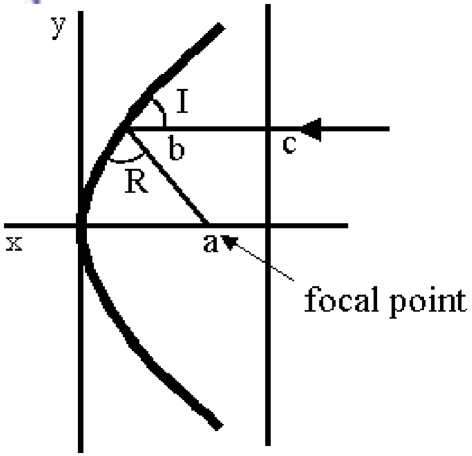
Array of patch Antennas



Reflector antennas

- used in order to transmit and receive signals that had to travel millions of miles
- A very common reflector antenna – parabolic reflector





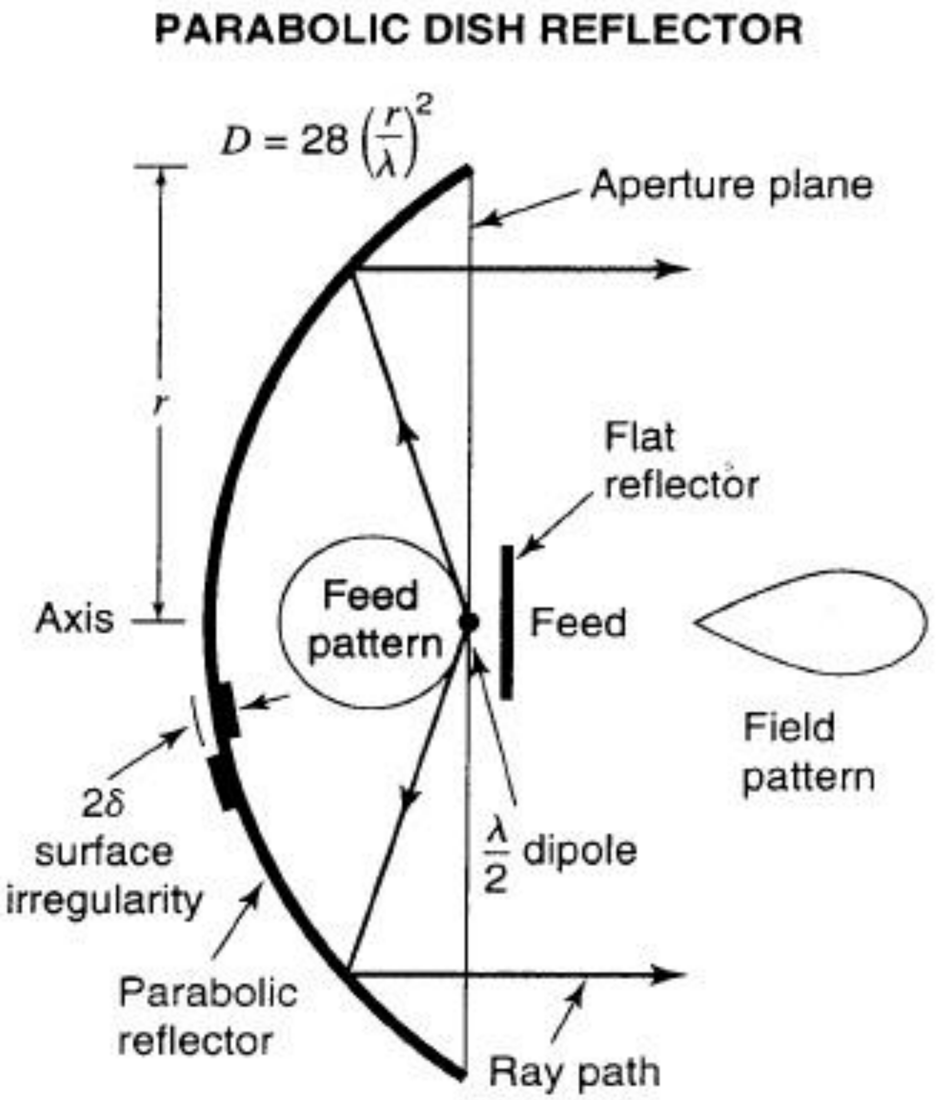
Reflector Antennas

Reflector [5]

Reflector [6]

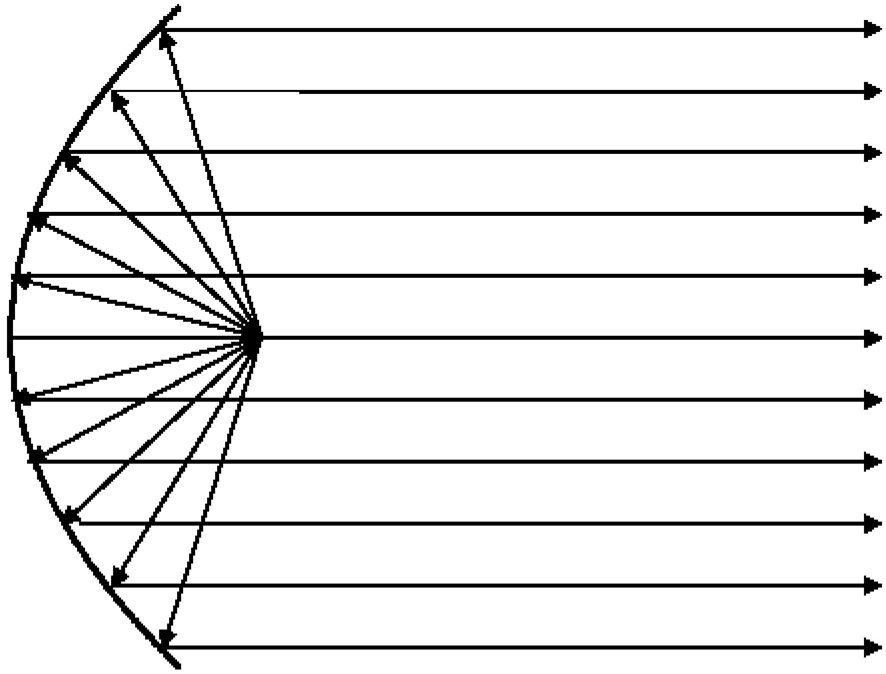
Parabolic Reflectors

- A parabolic reflector operates much the same way a reflecting telescope does
- Reflections of rays from the feed point all contribute in phase to a plane wave leaving the antenna along the antenna bore sight (axis)
- Typically used at UHF and higher frequencies



Parabolic Antenna

- Infinite Uniform Array



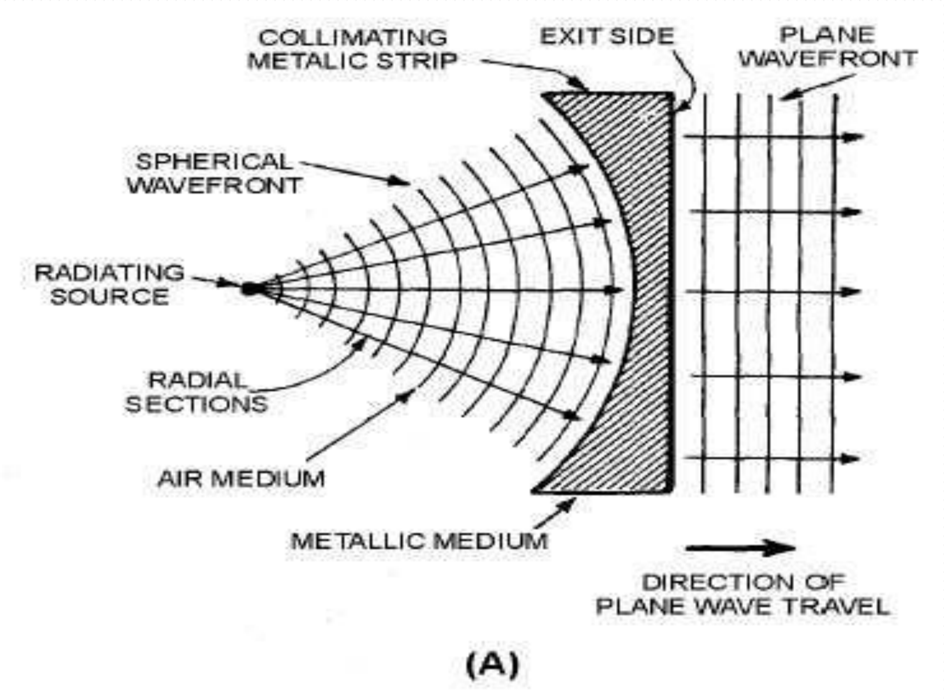
$$P = \frac{\sin \frac{\pi D \cos \phi}{\lambda}}{\frac{\pi D \cos \phi}{\lambda}}$$

Lens antennas

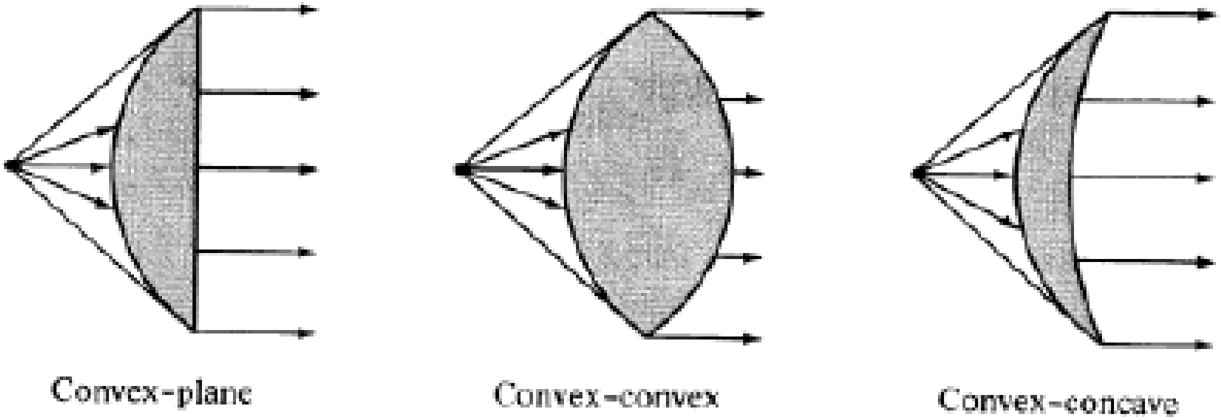
- lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions

- Transform various forms of divergent energy into plane waves

- Used in most of applications as are the parabolic reflectors, especially at higher frequencies. Their dimensions and weight bec0me exceedingly large at lower frequencies.



Lens antennas



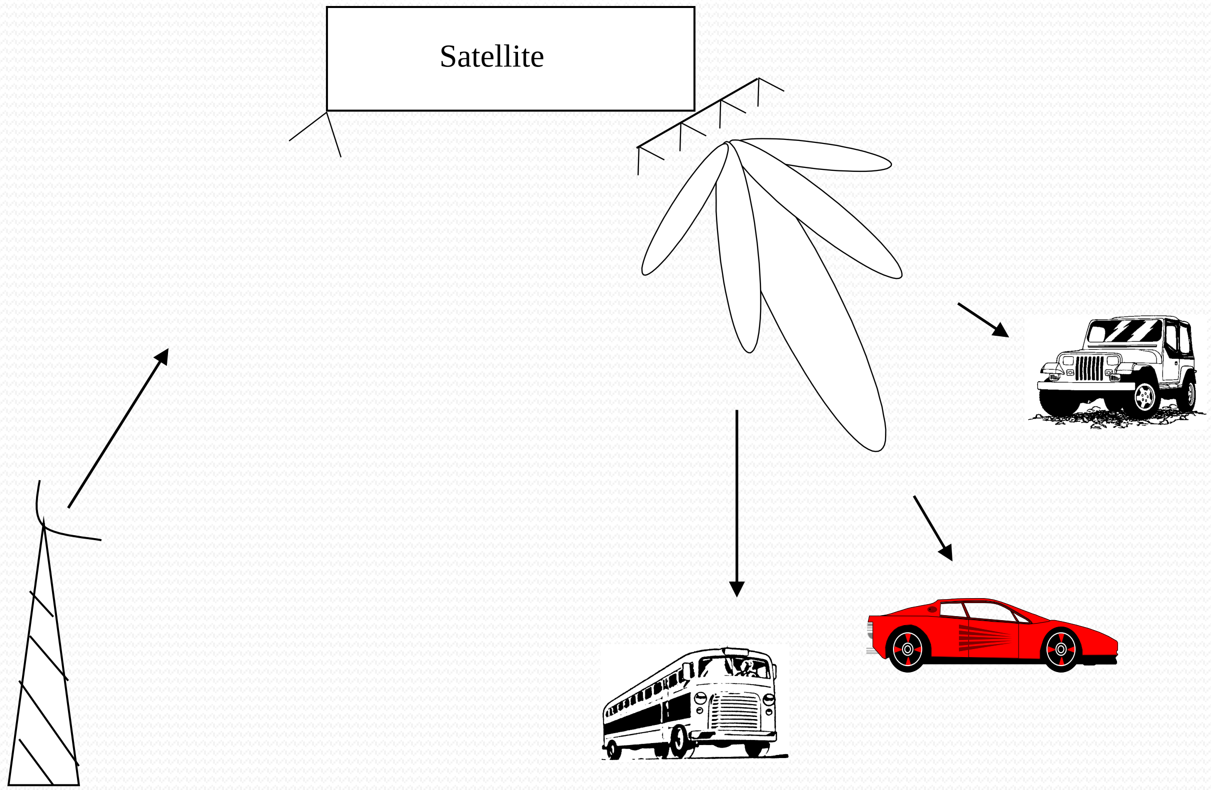
(a) Lens antennas with index of refraction $n > 1$

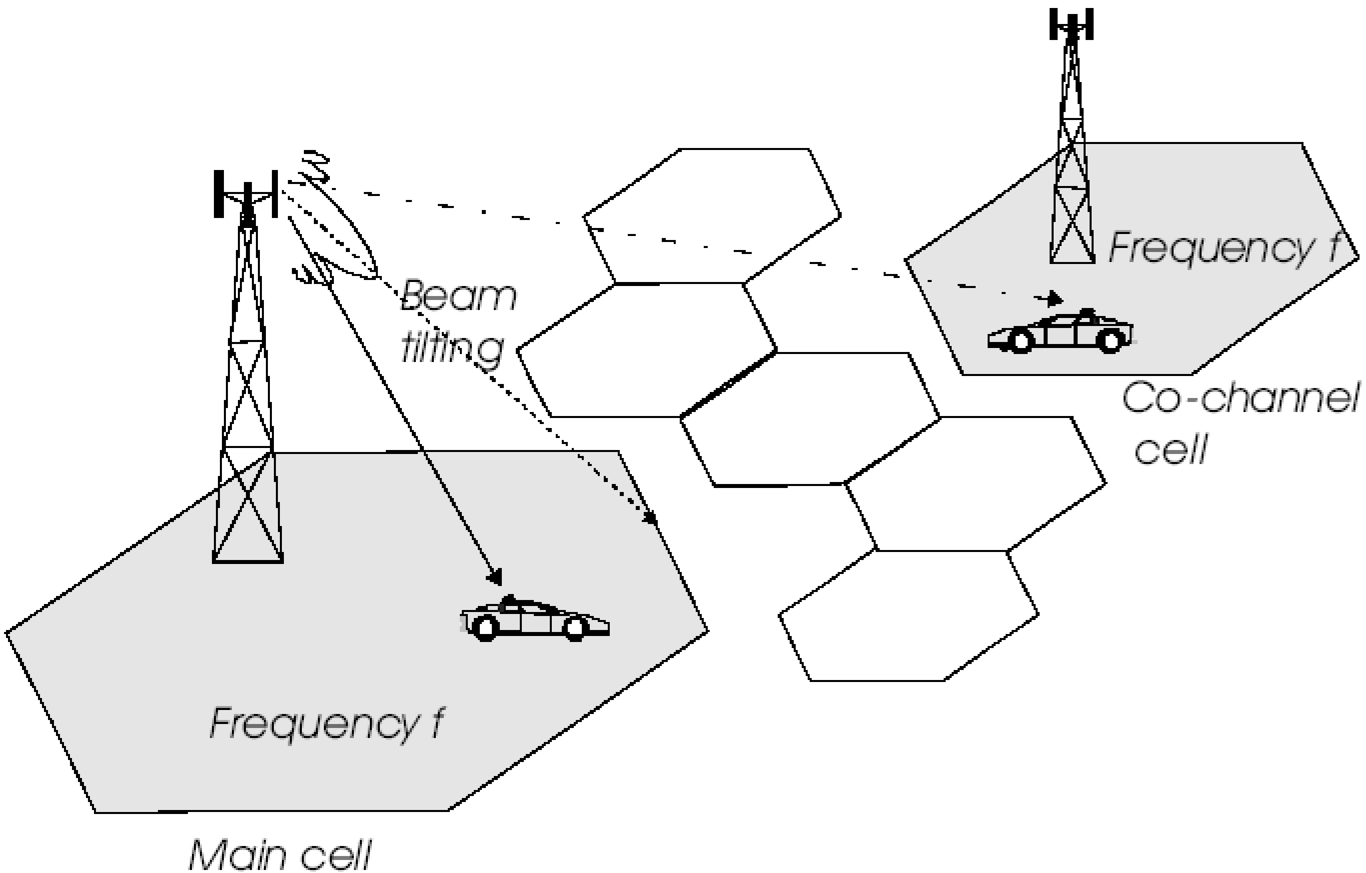
Lenses play a similar role to that of reflectors in reflector antennas: they collimate divergent energy
Often preferred to reflectors at frequencies > 100 GHz.

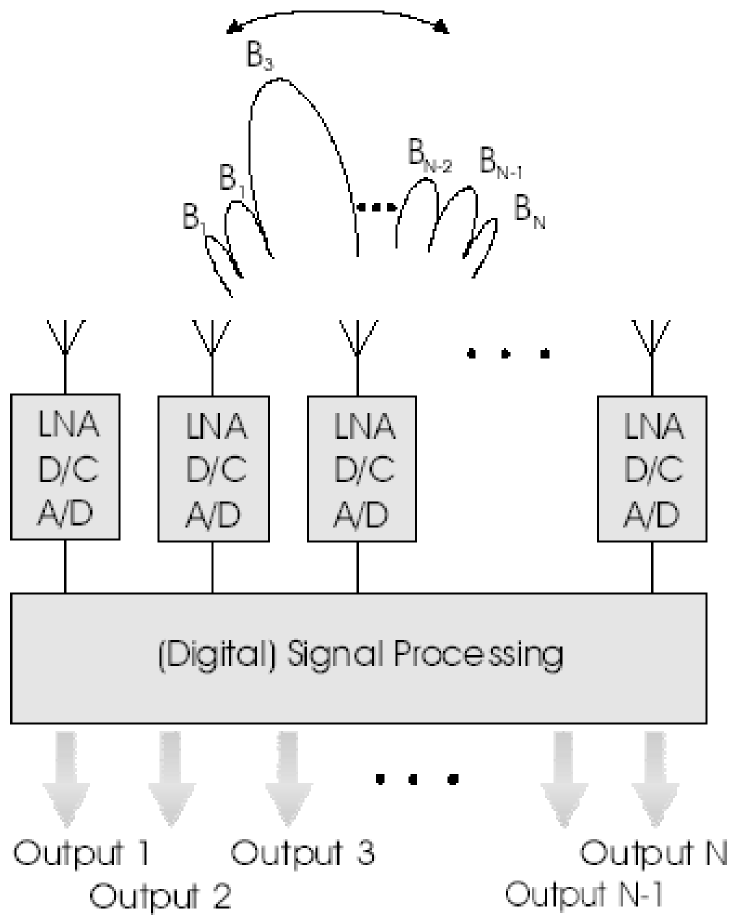
Advanced Antenna Systems

- Are expensive
- Increase cell coverage and capacity without building additional sites
- Examples
  - Multi-beam antenna systems
  - Smart antenna systems

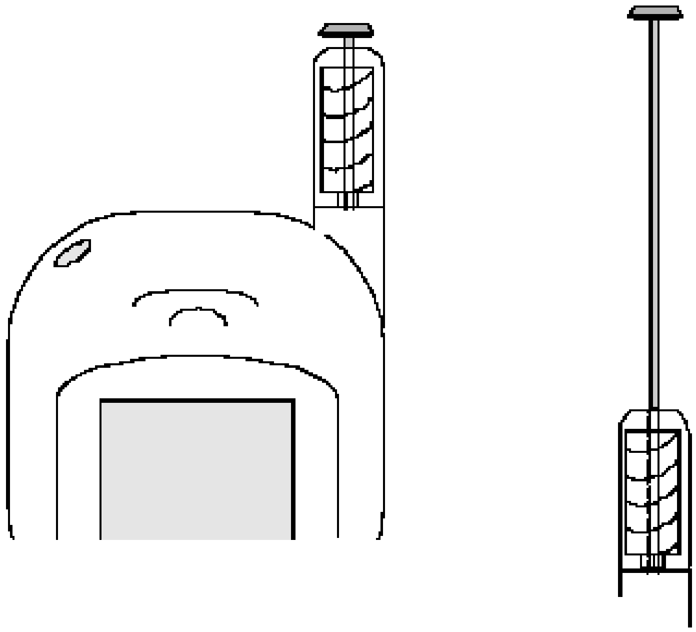
Smart Antennas



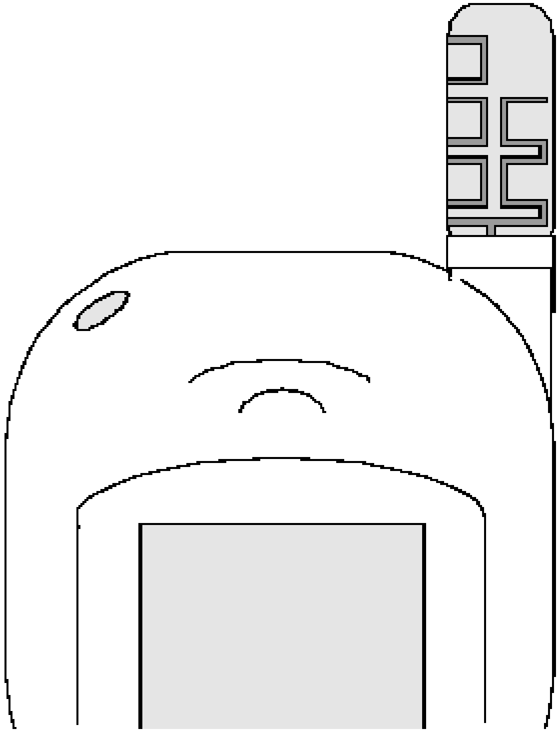

Beam
tilting
Frequency f
Co-channel
cell
Frequency f
Main cell



B_3
B_1
B_1
B_{N-2}
B_{N-1}
B_N
LNA D/C A/D
LNA D/C A/D
LNA D/C A/D
LNA D/C A/D
(Digital) Signal Processing
Output 1
Output 2
Output 3
Output N-1
Output N



Helical and whip antennas for dual band applications



A meander antenna

Antennas

- Introduction
- Types of Antenna
- Radiation Mechanism
  - →Physical concept of Radiation in single wire, two wire and dipole
- Current Distribution on a Thin Wire Antenna

PHYSICAL CONCEPT OF RADIATION or RADIATION MECHANISM

How is Radiation Accomplished?

Principle of radiation

When electric charges undergo acceleration or deceleration, electromagnetic radiation will be produced. Hence it is the motion of charges (i.e., currents) that is the source of radiation

basic equation of radiation

$$IL = Qv$$

Where

I→time varying current

Q→charge

L→length of current element

v→time change of velocity

Radiation Mechanism in a) Single wire, b) Two wire and c) Dipole

Radiation Mechanism

- **Single wire:**

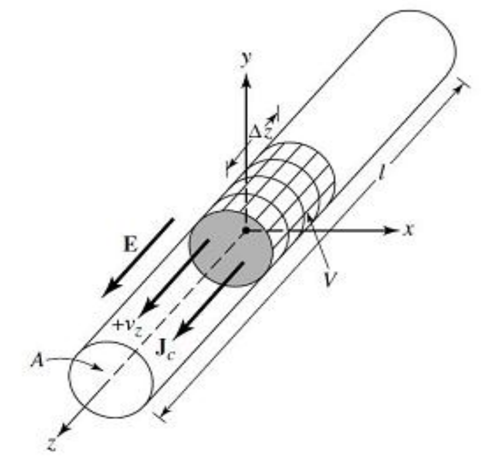
Conducting wires are characterized by the motion of electric charges and the creation of current flow.

Assume that an electric volume charge density, q_v (coulombs/m3), is distributed uniformly in a circular wire of cross-sectional area A and volume V

q_v - volume charge density

A- cross-sectional area

V-Volume



Charge uniformly distributed in a circular cross section cylinder wire.

Radiation Mechanism

- **Single wire:**

  - Current density in a volume with volume charge density q_v (C/m^3):
  $$J_z = q_v v_z \quad (\text{A/m}^2).$$
  - Surface current density in a section with a surface charge density q_s (C/m^2):
  $$J_s = q_s v_z \quad (\text{A/m}).$$
  - Current in a thin wire with a linear charge density q_l (C/m):
  $$I_z = q_l v_z \quad (\text{A}).$$

- Instead of examining all three current densities, we will primarily concentrate on the very thin wire.

- The conclusions apply to all three. If the current is time varying.

Radiation Mechanism

Thin Wire

If the current is time varying, then the derivative of the current of 3 can be written as

$$\frac{dIz}{dt} = q_l \frac{dv_z}{dt} = q_l a_z \quad (4$$

where a_z (m/s^2) is the acceleration. If the wire is of length l, then

$$l\frac{dIz}{dt} = lq_l \frac{dv_z}{dt} = lq_l a_z \quad (5$$

Equation 5 is the basic relation between current and charge, and it also serves as the fundamental relation of electromag netic radiation.

$l\frac{dIz}{dt} = lq_l \frac{dv_z}{dt} = lq_l a_z$

To create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge.

Radiation Mechanism

Thin wire

- We usually refer to currents in time-harmonic applications while charge is most often mentioned in transients.
- To create charge acceleration (or deceleration) the wire must be curved, bent, discontinuous, or terminated.
- Periodic charge acceleration (or deceleration) or time-varying current is also created when charge is oscillating in a time-harmonic motion.

1. If a charge is not moving, current is not created and there is no radiation.
2. If charge is moving with a uniform velocity:
   (a) There is no radiation if the wire is straight, and infinite in extent.
   (b) There is radiation if the wire is curved, bent, discontinuous, terminated, or truncated.
3. If charge is oscillating in a time-motion, it radiates even if the wire is straight.

Radiation Mechanism

- **Single wire:**

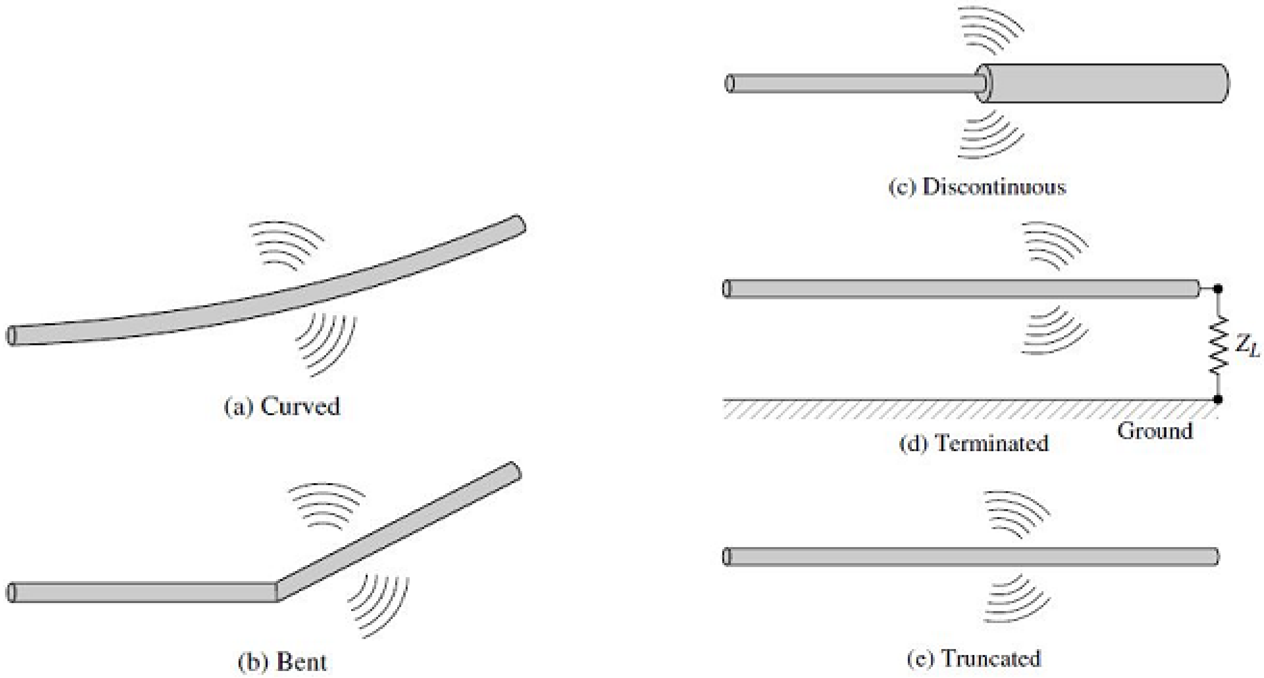
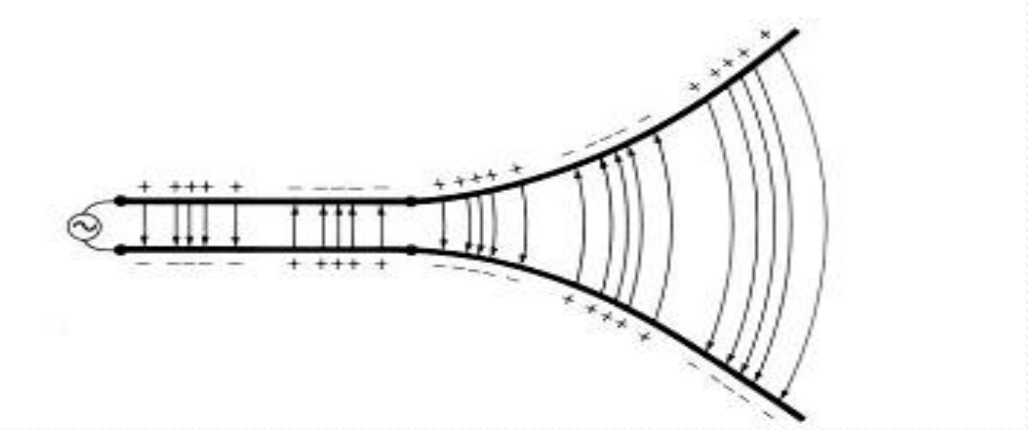


Figure 3: Wire Configurations for Radiation

Radiation Mechanism

Two-Wires:

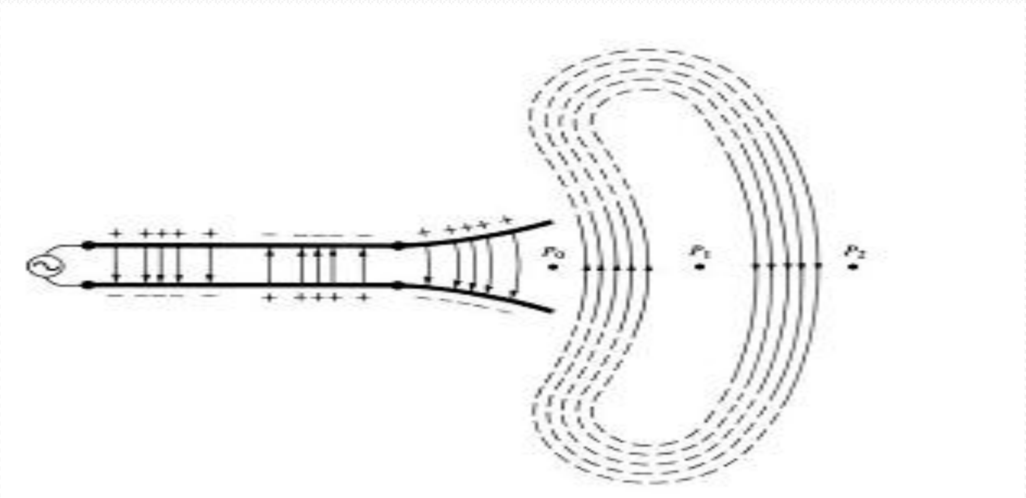
- Applying a voltage across the two-conductor transmission line creates an electric field between the conductors.
- The movement of the charges creates a current that in turn creates a magnetic field intensity.
- The creation of time-varying electric and magnetic fields between the conductors forms electromagnetic waves which travel along the transmission line.



Radiation Mechanism

Two-Wires:

- The electromagnetic waves enter the antenna and have associated with them electric charges and corresponding currents.
- If we remove part of the antenna structure, free-space waves can be formed by “connecting” the open ends of the electric lines



Radiation Mechanism

Two-Wires:

- If the initial electric disturbance by the source is of a short duration, the created electromagnetic waves travel inside the transmission line, then into the antenna, and finally are radiated as free-space waves, even if the electric source has ceased to exist.

- If the electric disturbance is of a continuous nature, electromagnetic waves exist continuously and follow in their travel behind the others.

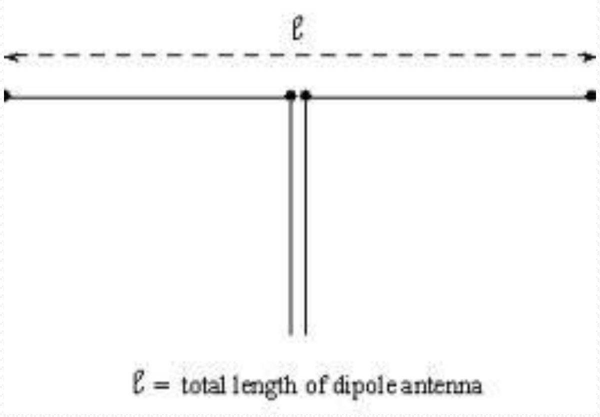
- However, when the waves are radiated, they form closed loops and there are no charges to sustain their existence.

- Electric charges are required to excite the fields but are not needed to sustain them and may exist in their absence.

Radiation Mechanism

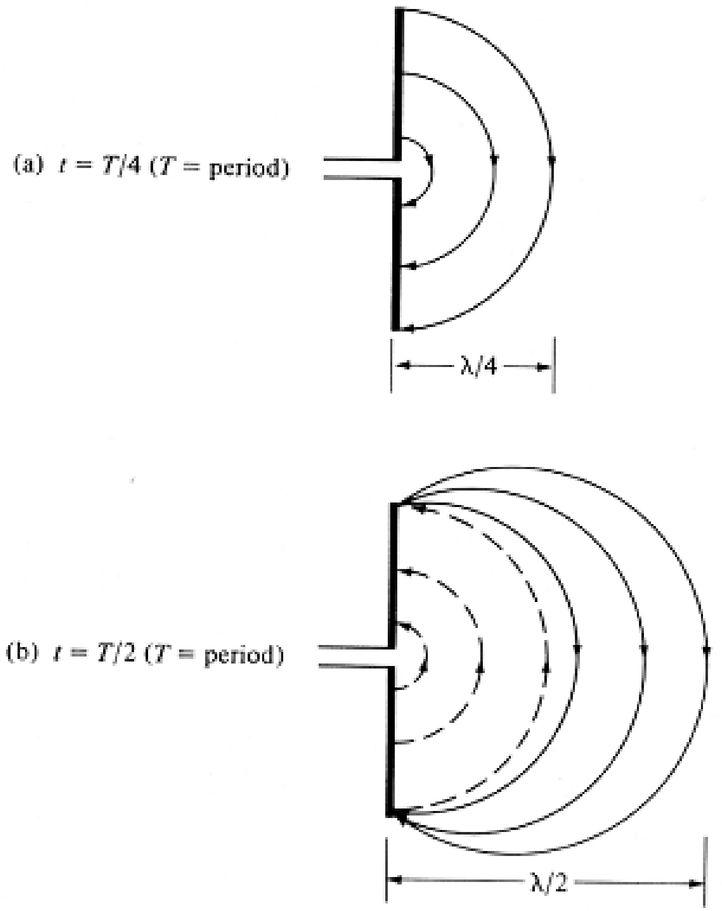
Dipole Antenna:

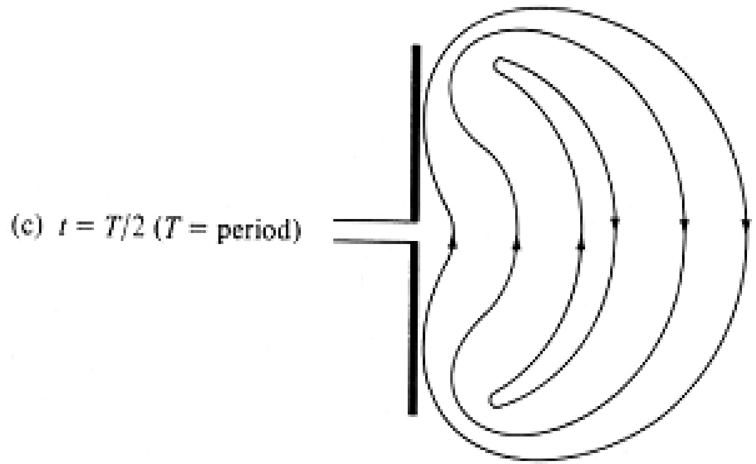
- A radio antenna that can be made of a simple wire, with a centre-fed driven element
- Consist of two metal conductors of rod or wire, oriented parallel and collinear with each other (in line with each other), with a small space between them.
- Consider the example of a small dipole antenna where the time of travel is negligible



Radiation Mechanism

Formation and detachment of electric field line for short Dipole Antenna





Dipole

During the fist $T/4$
The charge has reached a maximum. Lines have traveled outwardly a radial distance $\lambda/4$.

During $T/4$ to $T/2$
The original three lines travel an additional $\lambda/4$. The lines created by the opposite charges travel a distance $\lambda/4$. The charge density begins to diminish, leading to neutralization.

At $T/2$
There is no net charge on the antenna. The lines must have been forced to detach themselves from the conductors and to unite together to form closed loops.

Beyond $T/2$
The process repeats.

Current Distribution on a thin wire antenna

- Let us consider the geometry of a lossless two-wire transmission line

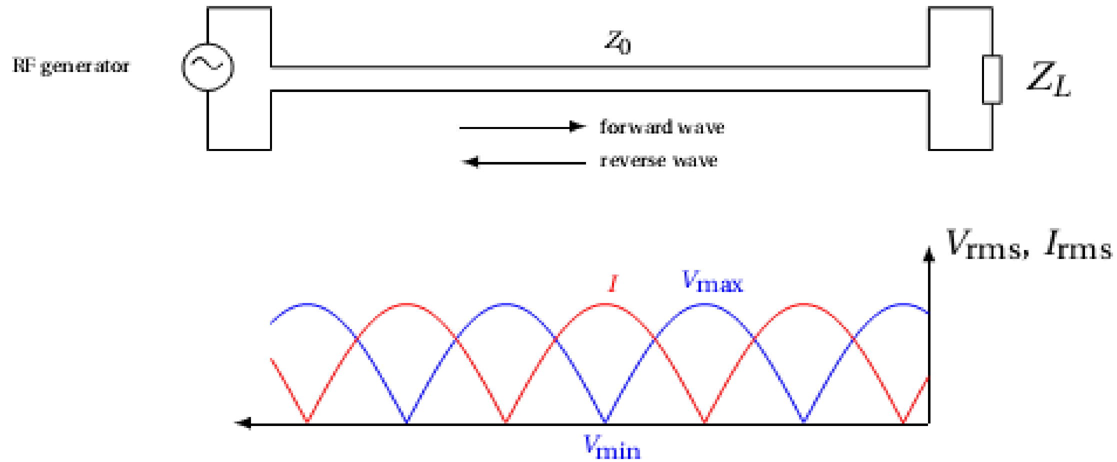
- The movement of the charges creates a traveling wave current, of magnitude I_0 /2, along each of the wires.

- When the current arrives at the end of each of the wires, it undergoes a complete reflection (equal magnitude and 180 phase reversal)

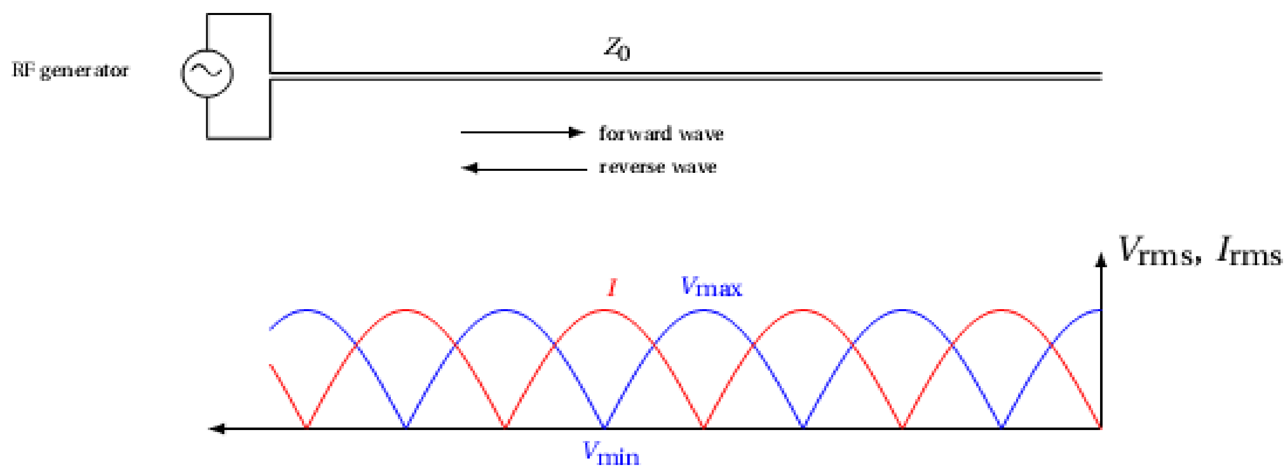
- The reflected traveling wave, when combined with the incident traveling wave, forms in a each wire a pure standing wave pattern of sinusoidal form.

Current Distribution on a thin wire antenna

Standing Waves

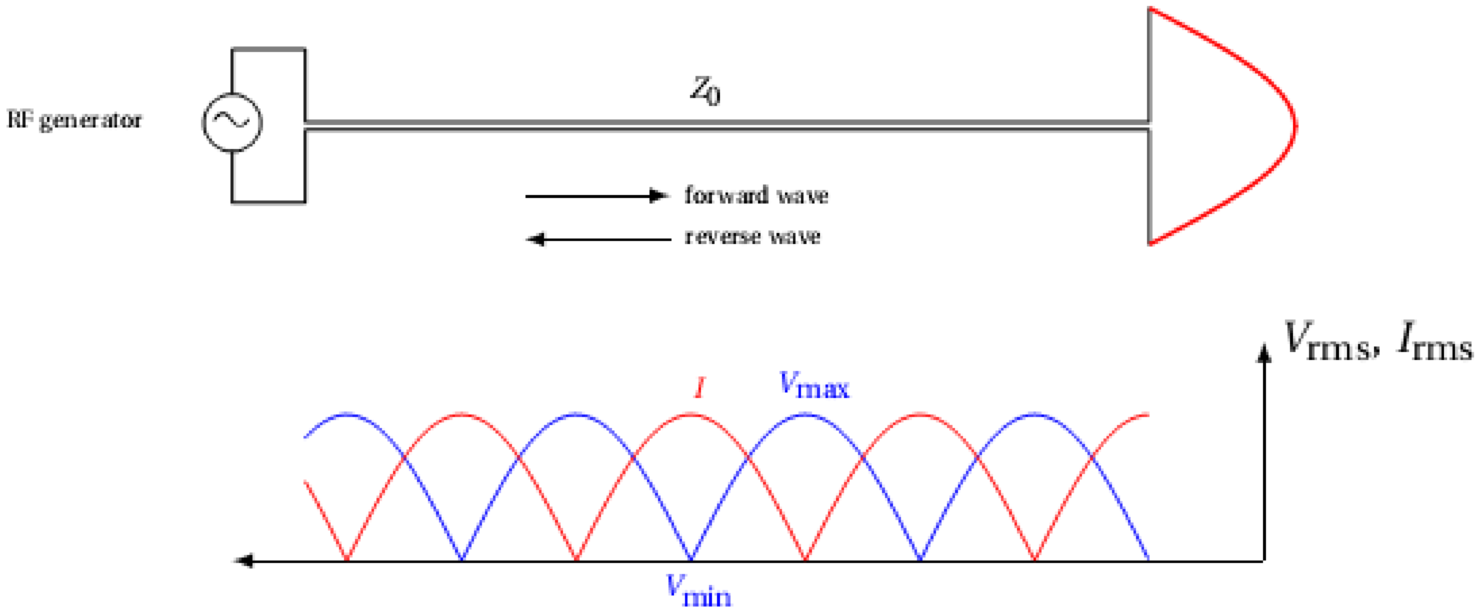


Standing waves on a transmission line.



Open circuit transmission line.

Current Distribution on a thin wire antenna

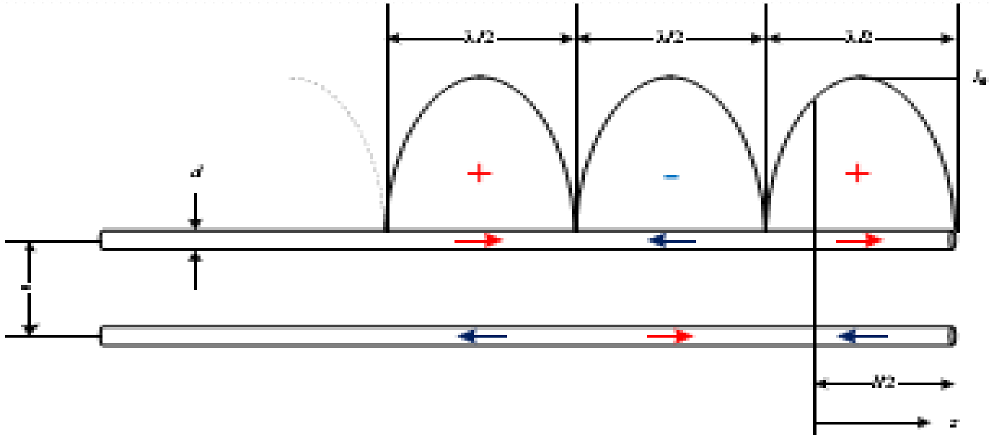


Radiation from a half-wave dipole.

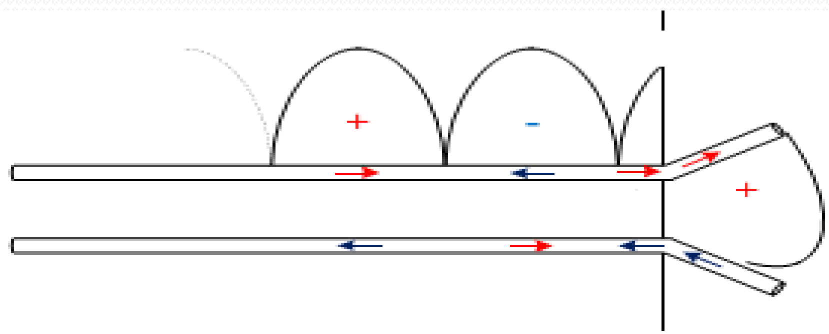
- For the two-wire balanced (symmetrical) transmission line, the current in a half-cycle of one wire is of the same magnitude but 180 out-of-phase from that in the corresponding half-cycle of the otherwire

Current Distribution on a thin wire antenna

- If s is also very small, the two fields are canceled
- The net result is an almost ideal, non-radiating transmission line.



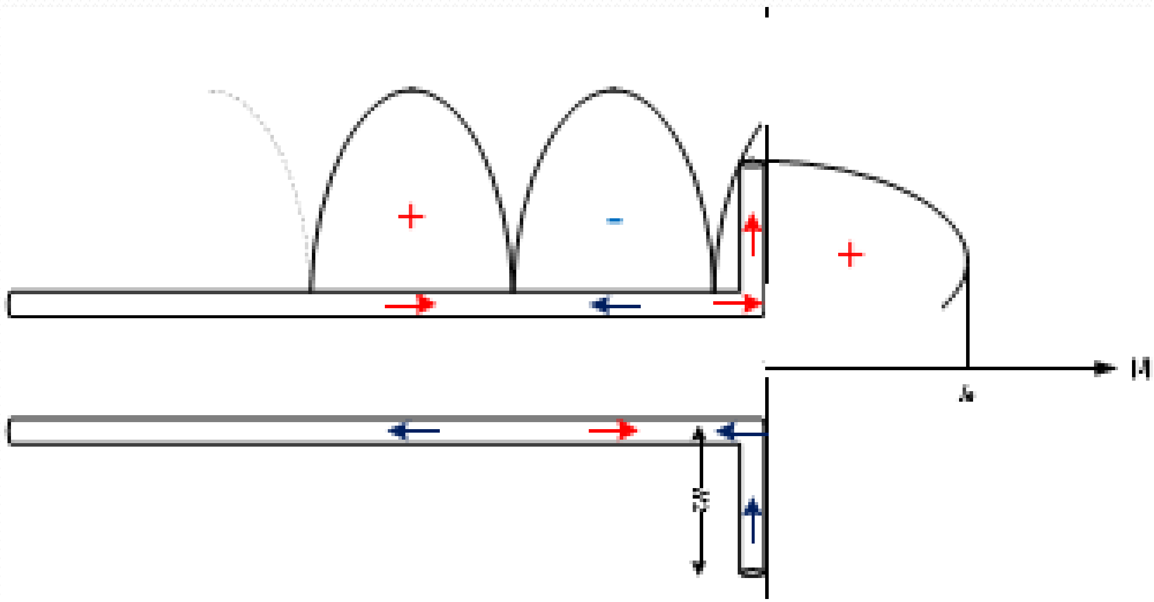
- When the line is flared, because the two wires of the flared section are not necessarily close to each other, the fields do not cancel each other
- Therefore ideally there is a net radiation by the transmission line system

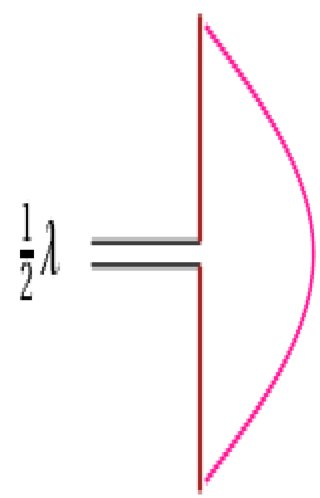


Current Distribution on a thin wire antenna

- When the line is flared into a dipole, if s not much less than λ, the phase of the current standing wave pattern in each arm is the same through out its length. In addition, spatially it is oriented in the same direction as that of the other arm

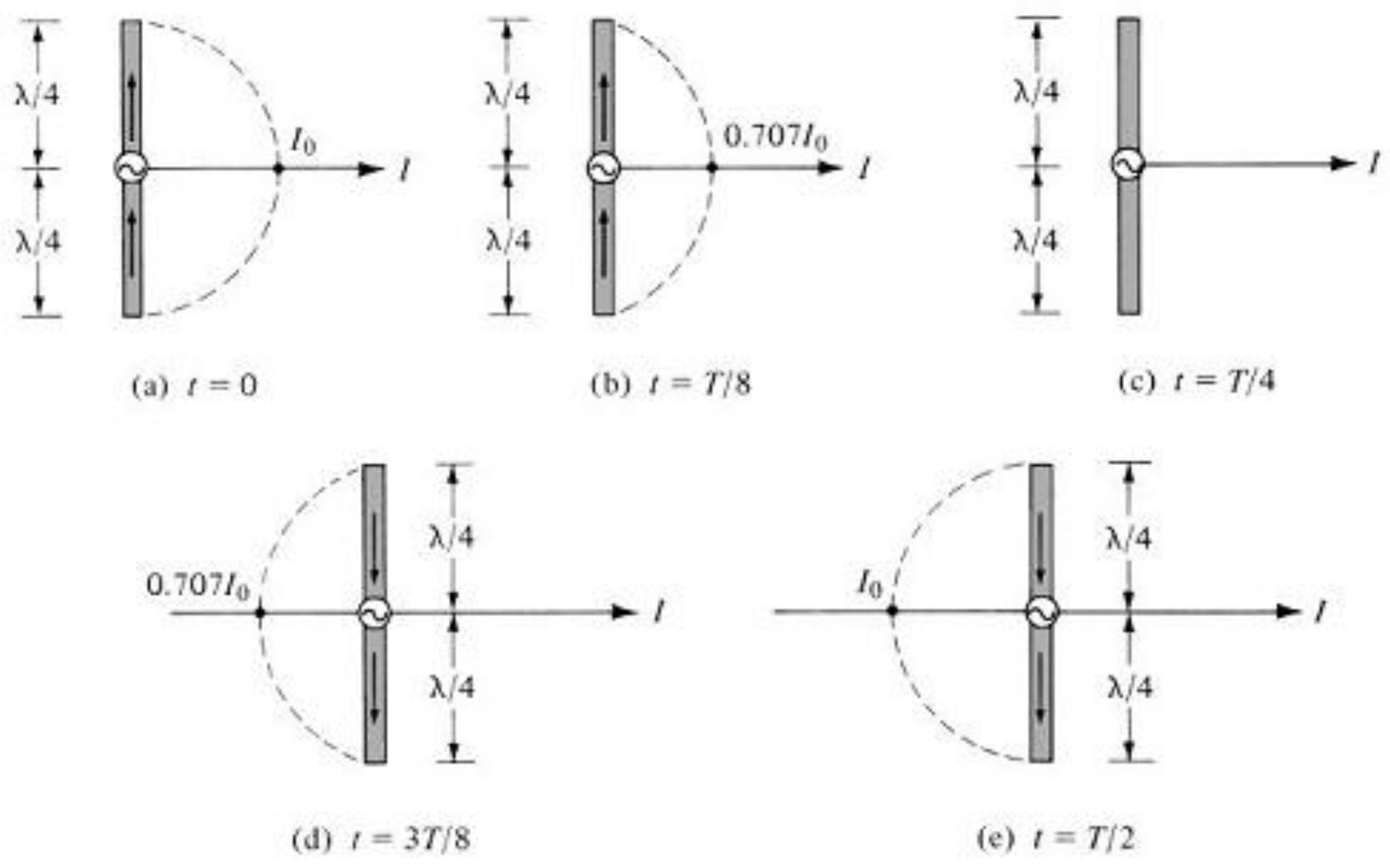
- Thus the field s radiated by the two arms of the dipole (vertical parts of a flared transmission line) will primarily reinforce each other toward most directions of observation





Current Distribution on a thin wire antenna

- The current distributions we have seen represent the maximum current excitation for anytime. The current varies as a function of time as well.



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- Antennas
- Fundamental Parameters of Antennas
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Fundamental Parameters of Antennas

- Introduction
- Radiation Pattern
- Radiation Power Density
- Radiation intensity
- Directivity, Gain, Antenna efficiency, Beamwidth
- Bandwidth
- Linear, circular, and elliptical polarization
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Introduction

- To describe performance of an antenna
- Definition of various parameters

Fundamental Parameters of Antennas

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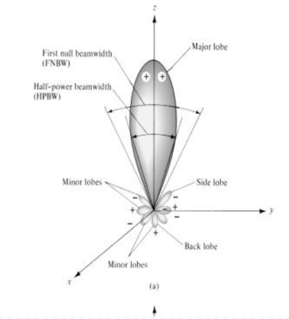
Radiation pattern



- Mathematical function or Graphical representation of radiation properties of an antenna as a function of space coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization."

- Radiation pattern usually indicate either electric field intensity or power intensity. Magnetic field intensity has the same radiation pattern as the electric field intensity

- A directional antenna radiates and receives preferentially in some direction

- Depicted as two or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius

- Lobes are classified as: major, minor, side lobes, back lobes

Radiation pattern

Coordinate system for antenna analysis

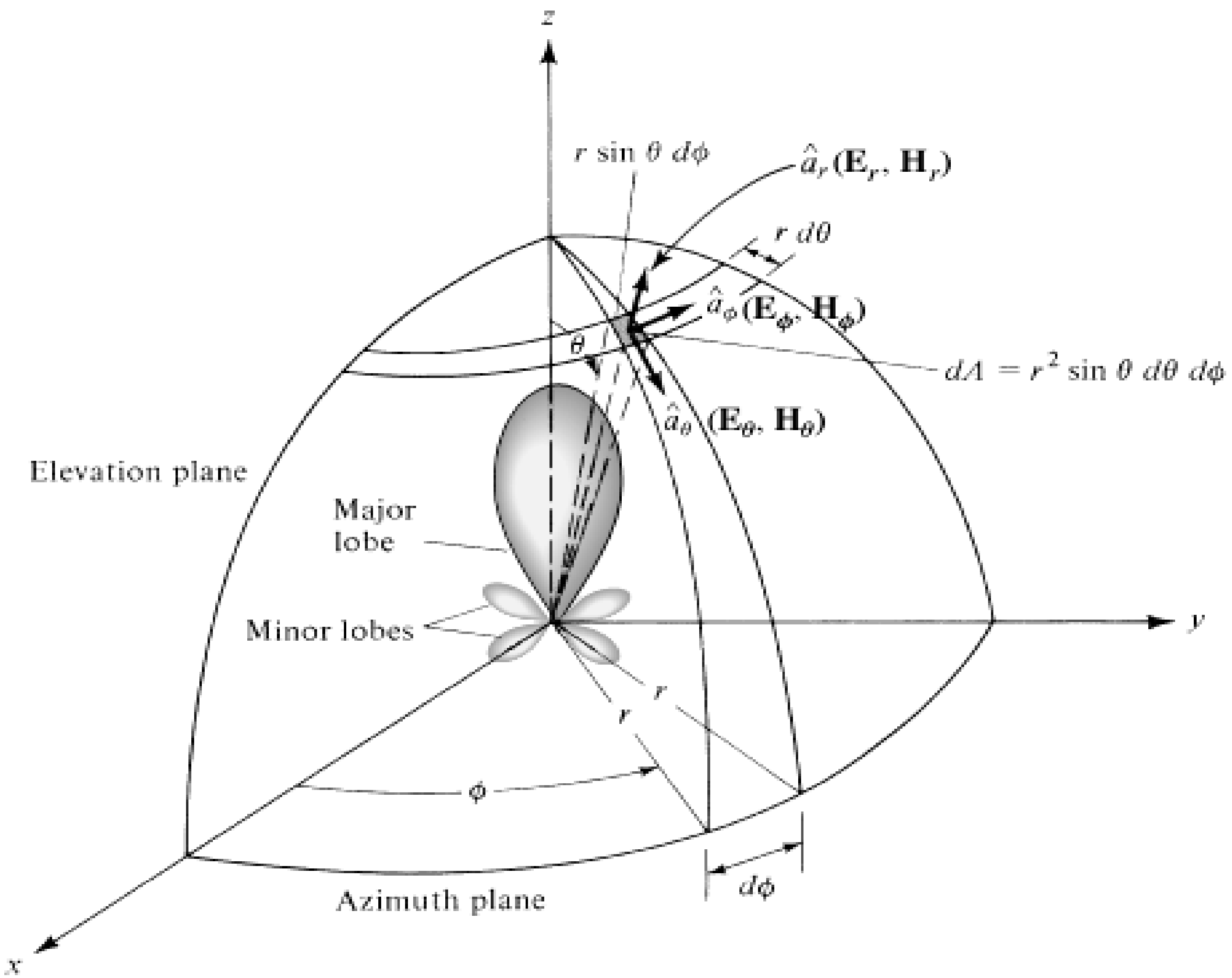


Figure 2.1 Coordinate system for antenna analysis.

Radiation pattern

For an antenna

The Field pattern(in linear scale):

typically represents a plot of the magnitude of the electric or magnetic field as a function of the angular space.

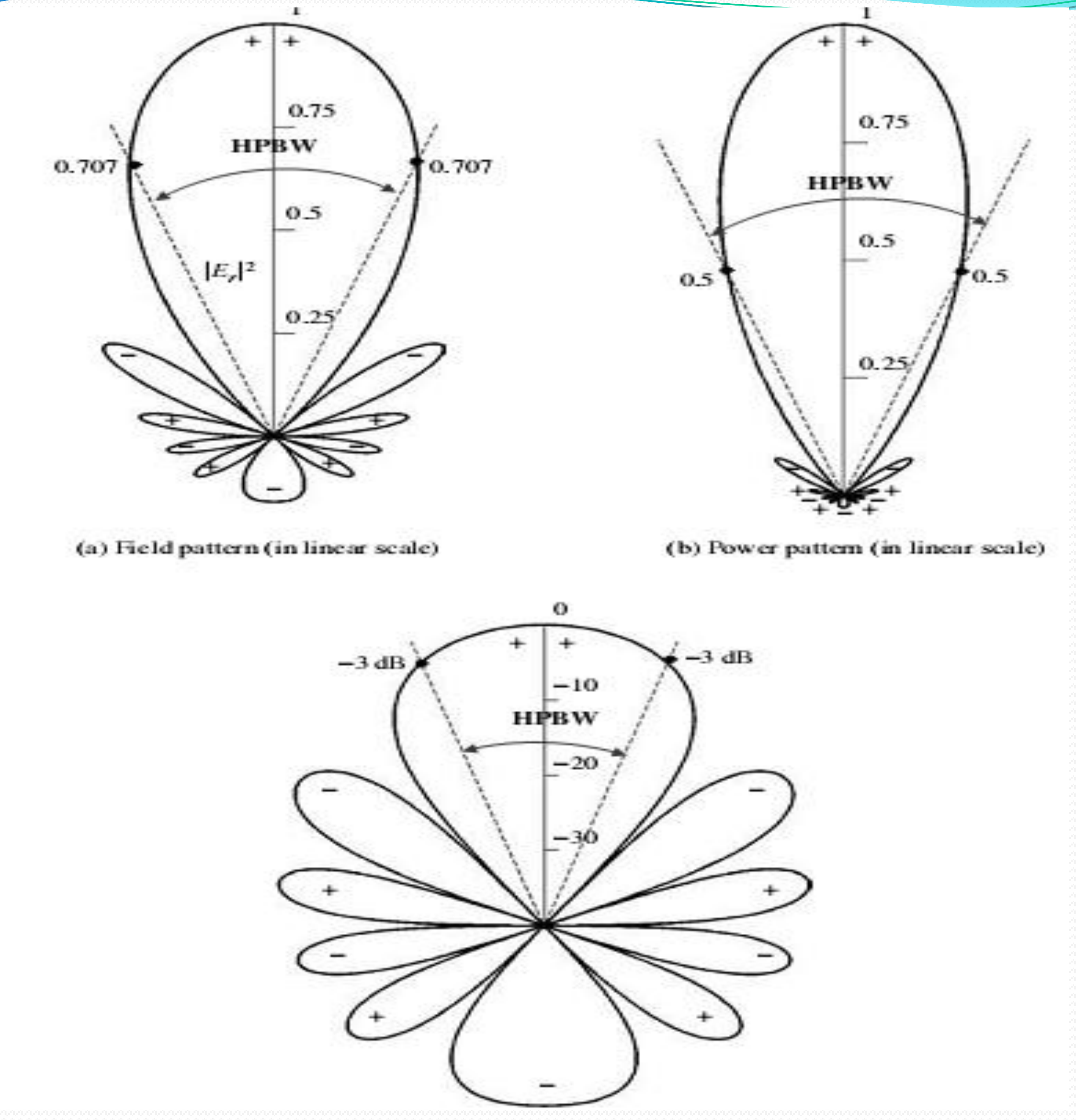
The Power pattern(in linear scale):

typically represents a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space

The Power pattern(in dB):

represents the magnitude of the electric or magnetic field, in decibels, as a function of the angular space.

Radiation pattern

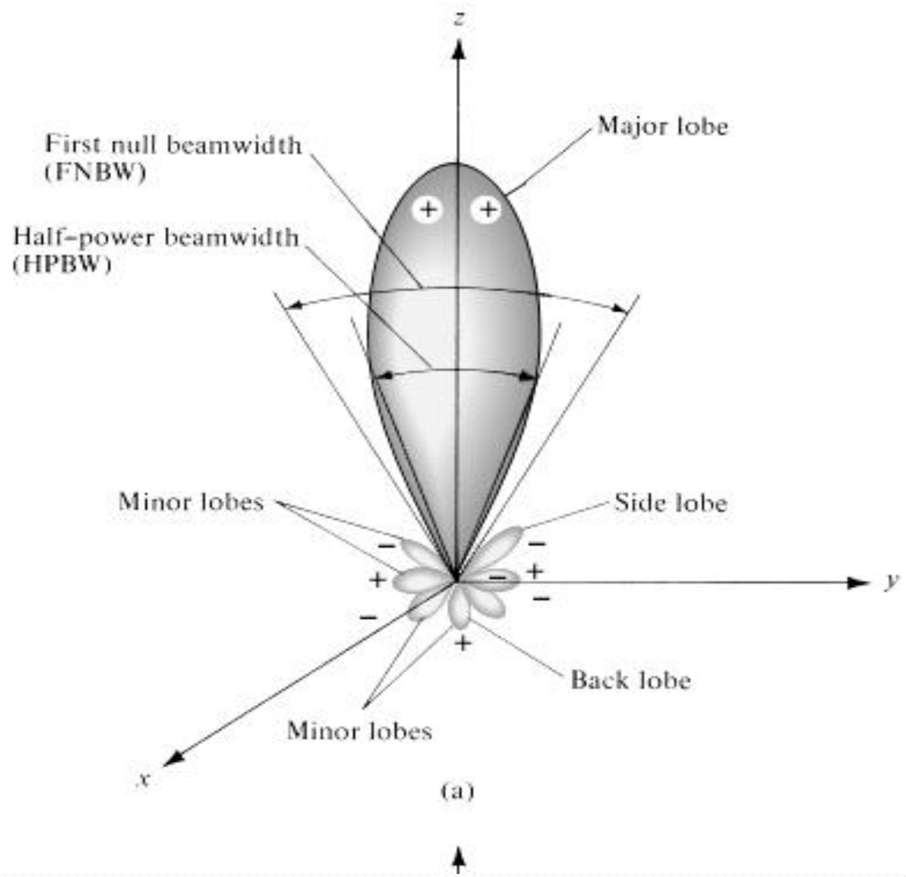


Radiation pattern

various parts of a radiation pattern are referred to as a lobes

Total electric field is given as

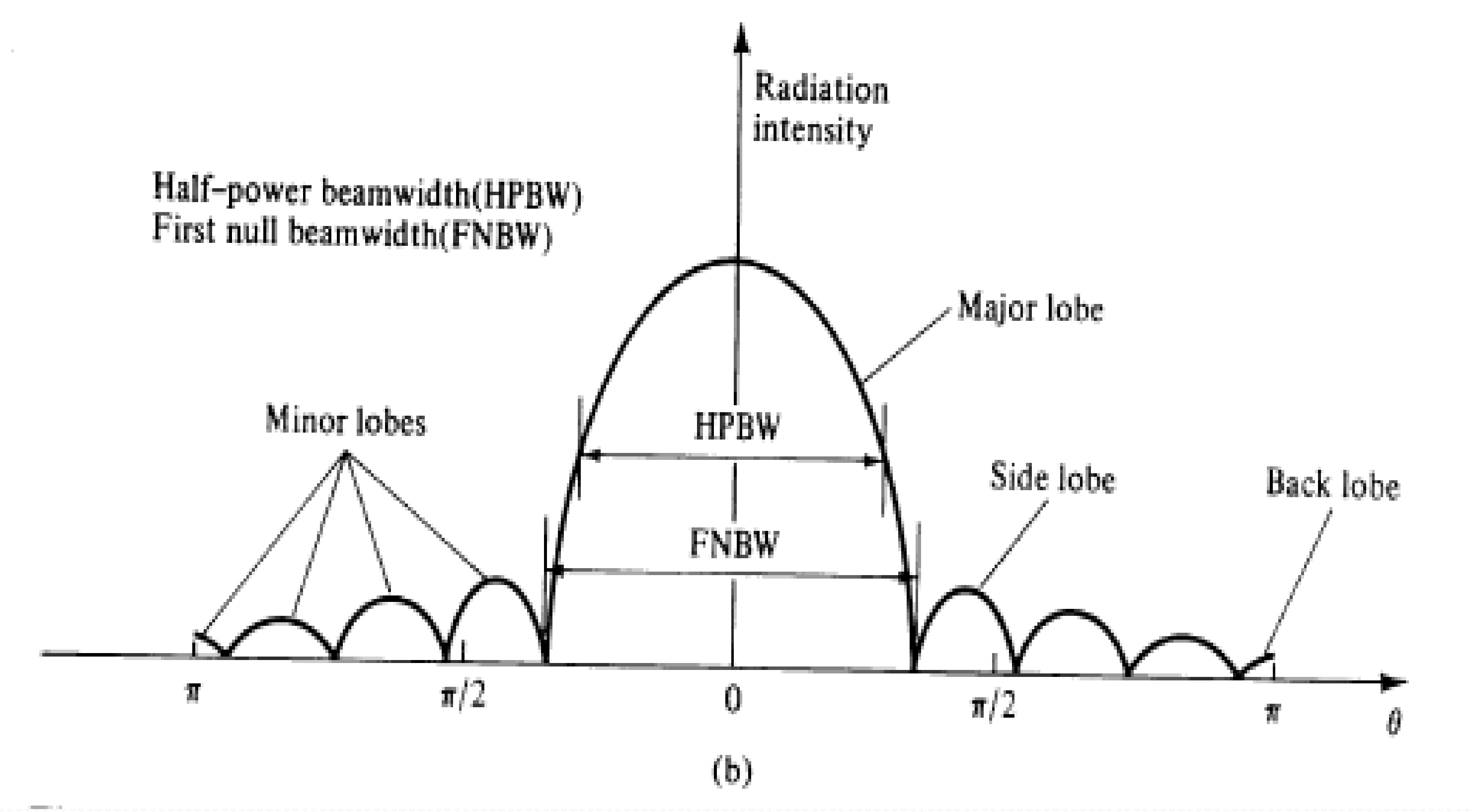
$$|\mathbf{E}| = \sqrt{|E_r|^2 + |E_\theta|^2 + |E_\phi|^2}.$$



Three dimensional polar pattern

Radiation pattern

various parts of a radiation pattern are referred to as a lobes



Two dimensional polar pattern

Radiation pattern lobes

Various parts of a radiation pattern are referred to as **lobes**

- **Major lobe (main lobe):**
  - The radiation lobe containing the direction of maximum radiation
  - Major lobe is pointing at θ=0 direction in figure
  - In spilt-beam antennas, there may exist more than one major lobes
- **Minor Lobe**
  - is any lobe except a major lobe
  - all the lobes exception of the major lobe
- **Side lobe**: a radiation lobe in any direction other than intended lobe
  - Usually it is adjacent to main lobe
- **Back lobe:**
  - a radiation lobe whose axis makes an angle of approximately 180^0 with respect to the beam of antenna
  - usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of major lobe

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Radiation Power Density

- Poynting Vector or Power density(w)

The instantaneous poynting vector describe the power associated with electromagnetic wave

Poynting vector defined as

$$W = \mathcal{E} \times \mathcal{H}$$

W- instantaneous poynting vector (W/m^2)

$\mathcal{E}$- instantaneous electric field intensity (V/m)

$\mathcal{H}$- instantaneous magnetic field intensity (A/m)

Radiation Power Density

- The total power crossing a closed surface can be obtained by integrating the normal component of poynting vector over the entire surface.

$$\mathscr{P} = \oiint_S \boldsymbol{\mathcal{W}} \cdot d\mathbf{s} = \oiint_S \boldsymbol{\mathcal{W}} \cdot \hat{\mathbf{n}}\, da$$

$\mathscr{p}$= instantaneous total power (W)

ˆn = unit vector normal to the surface

da = infinitesimal are a of the closed surface (m^2)

we define the complex fields E and H which are related to their instantaneous counter parts $\mathcal{E}$ and $\mathcal{H}$ by

$$\boldsymbol{\mathcal{E}}(x, y, z; t) = \mathrm{Re}[\mathbf{E}(x, y, z)e^{j\omega t}]$$

$$\boldsymbol{\mathcal{H}}(x, y, z; t) = \mathrm{Re}[\mathbf{H}(x, y, z)e^{j\omega t}]$$

Radiation Power Density

identity $\mathrm{Re}[\mathbf{E}e^{j\omega t}] = \frac{1}{2}[\mathbf{E}e^{j\omega t} + \mathbf{E}^* e^{-j\omega t}]$,

- W = $\mathcal{E} \times \mathcal{H} = \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}^*] + \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}e^{j2\omega t}]$

The first term of is not a function of time, and the time variations of the second are twice the given frequency.

Average Power Density:

The average power density is obtained by integrating the instantaneous Poynting vector over one period and dividing by the period.

Wav= $\frac{1}{2}\mathrm{Re}[\boldsymbol{E} \times \boldsymbol{H}^*] \quad (\mathrm{W/m^2})$

the real part of represents the average (real) power density the imaginary part Must represent the reactive (stored) power density associated with the electromagnetic fields

Radiation Power Density

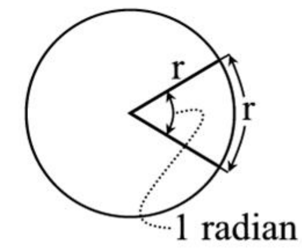
The average power radiated by an antenna (radiated power) can be written as

$$P_{\text{rad}} = P_{\text{av}} = \oiint_S \mathbf{W}_{\text{rad}} \cdot d\mathbf{s} = \oiint_S \mathbf{W}_{\text{av}} \cdot \hat{\mathbf{n}}\, da$$
$$= \frac{1}{2} \oiint_S \text{Re}(\mathbf{E} \times \mathbf{H}^*) \cdot d\mathbf{s}$$

Radian and Steradian

A **radian** is defined with the using Figure (a)

→It is the angle subtended by an arc along the perimeter of the circle with length equal to the radius.



(a)

A **steradian** may be defined using Figure (b)

→Here, one steradian (sr) is subtended by an area r^2 at the surface of a sphere of radius r.

The infinitesimal area dA on the surface of radius r is defined as

$$dA = r^2 \sin\theta \, d\theta \, d\phi \ (m^2)$$

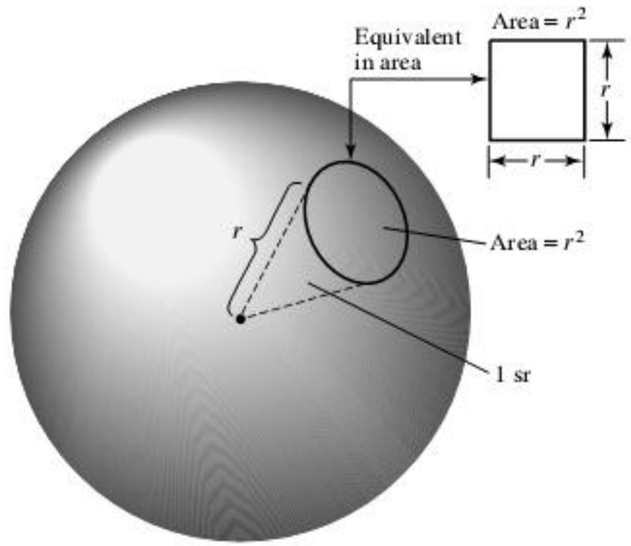
A differential solid angle, $d\Omega$, in sr, is given by

$$d\Omega = dA/r^2 = \sin\theta \, d\theta \, d\phi \ (sr)$$

$$\Omega = \iint \sin\theta \, d\theta \, d\phi$$

Unit of plane Angle is a radian

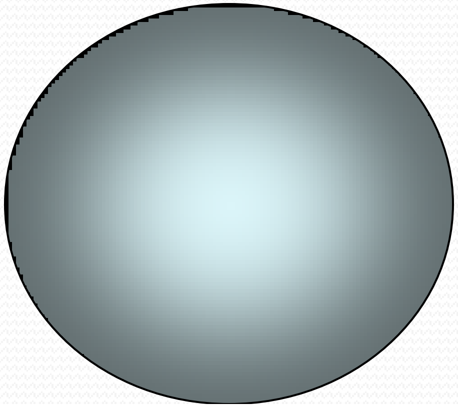
Unit of Solid Angle is a steradian



(b) Steradian

Isotropic antenna

- **Isotropic antenna** **or** **isotropic radiator** **or** **isotropic source** **or** **omnidirectional radiator** **or** **simple unipole**



→ is a hypothetical (not physically realizable) lossless antenna having equal radiation in all directions

→ used as a useful reference antenna to describe real antennas.

→ Its radiation pattern is represented by a sphere of radius (r) whose center coincides with the location of the isotropic radiator.

→ All the energy(power) must pass over the surface area of sphere=$4\pi r^2$

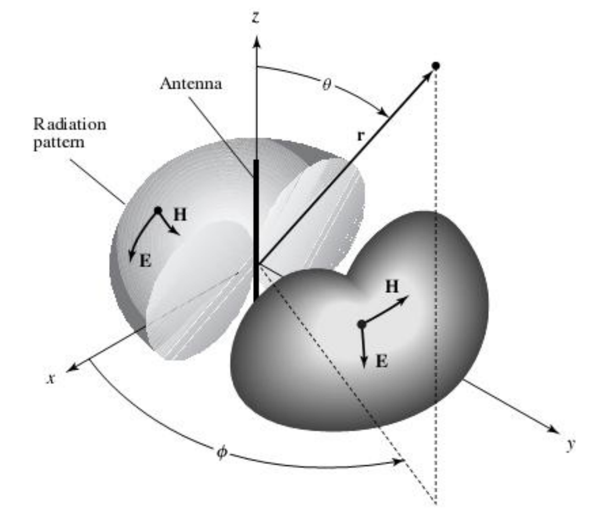


Figure 2.6 Omnidirectional antenna pattern.

Isotropic antenna

- Poynting vector or power density(w) at any point on the sphere
  →"power radiated per unit area in any direction"

- The magnitude of the poynting vector is equal to the radial component only(because $p_\theta = p_\Phi = 0$)

$$|w| = w_r$$

The total radiated power

$$p = \iint w.ds$$
$$= \iint w_r.ds$$
$$= w_r \iint ds$$
$$= w_r 4\pi r^2$$
$$w_r = p/4\pi r^2 \text{ watt/m}^2$$

where

W_r→ radiated power of average power density

P→ total power radiated

Isotropic antenna

- The total power radiated by it is given by:

$$P_{\mathrm{rad}} = \oiint_S \mathbf{W}_0 \cdot d\mathbf{s} = \int_0^{2\pi} \int_0^{\pi} [\hat{\mathbf{a}}_r W_0(r)] \cdot [\hat{\mathbf{a}}_r r^2 \sin\theta \, d\theta \, d\phi] = 4\pi r^2 W_0$$

- The power density is given by:

$$\mathbf{W}_0 = \hat{\mathbf{a}}_r W_0 = \hat{\mathbf{a}}_r \left(\frac{P_{\mathrm{rad}}}{4\pi r^2} \right) \quad (\mathrm{W/m^2})$$

which is uniformly distributed over the surface of a sphere of radius r.

Isotropic antenna

Example 2.2

The radial component of the radiated power density of an antenna is given by

$$\mathbf{W}_{\text{rad}} = \hat{\mathbf{a}}_r W_r = \hat{\mathbf{a}}_r A_0 \frac{\sin\theta}{r^2} \quad (\text{W/m}^2)$$

where A_0 is the peak value of the power density, θ is the usual spherical coordinate, and $\hat{\mathbf{a}}_r$ is the radial unit vector. Determine the total radiated power.

Solution: For a closed surface, a sphere of radius r is chosen. To find the total radiated power, the radial component of the power density is integrated over its surface. Thus

$$P_{\text{rad}} = \oiint_S \mathbf{W}_{\text{rad}} \cdot \hat{\mathbf{n}}\, da$$

$$= \int_0^{2\pi} \int_0^{\pi} \left(\hat{\mathbf{a}}_r A_0 \frac{\sin\theta}{r^2} \right) \cdot (\hat{\mathbf{a}}_r r^2 \sin\theta \, d\theta \, d\phi) = \pi^2 A_0 \quad (\text{W})$$

A three-dimensional normalized plot of the average power density at a distance of $r = 1$ m is shown in Figure 2.6.

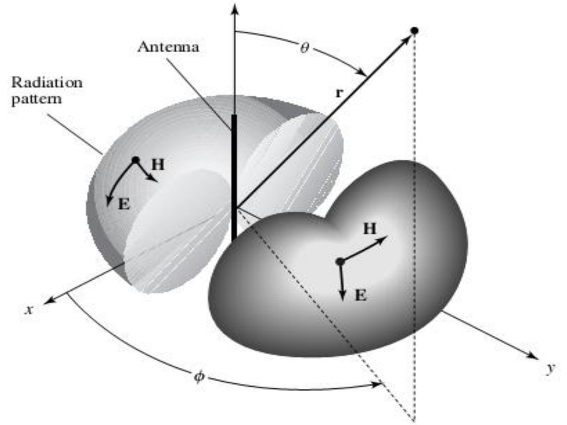


Figure 2.6 Omnidirectional antenna pattern.

Directional antenna

- is an antenna, which radiates (or receives) much more power in (or from) some directions than in (or from) others

Note:

Usually, this term is applied to antennas whose directivity is much higher than that of a half-wave dipole

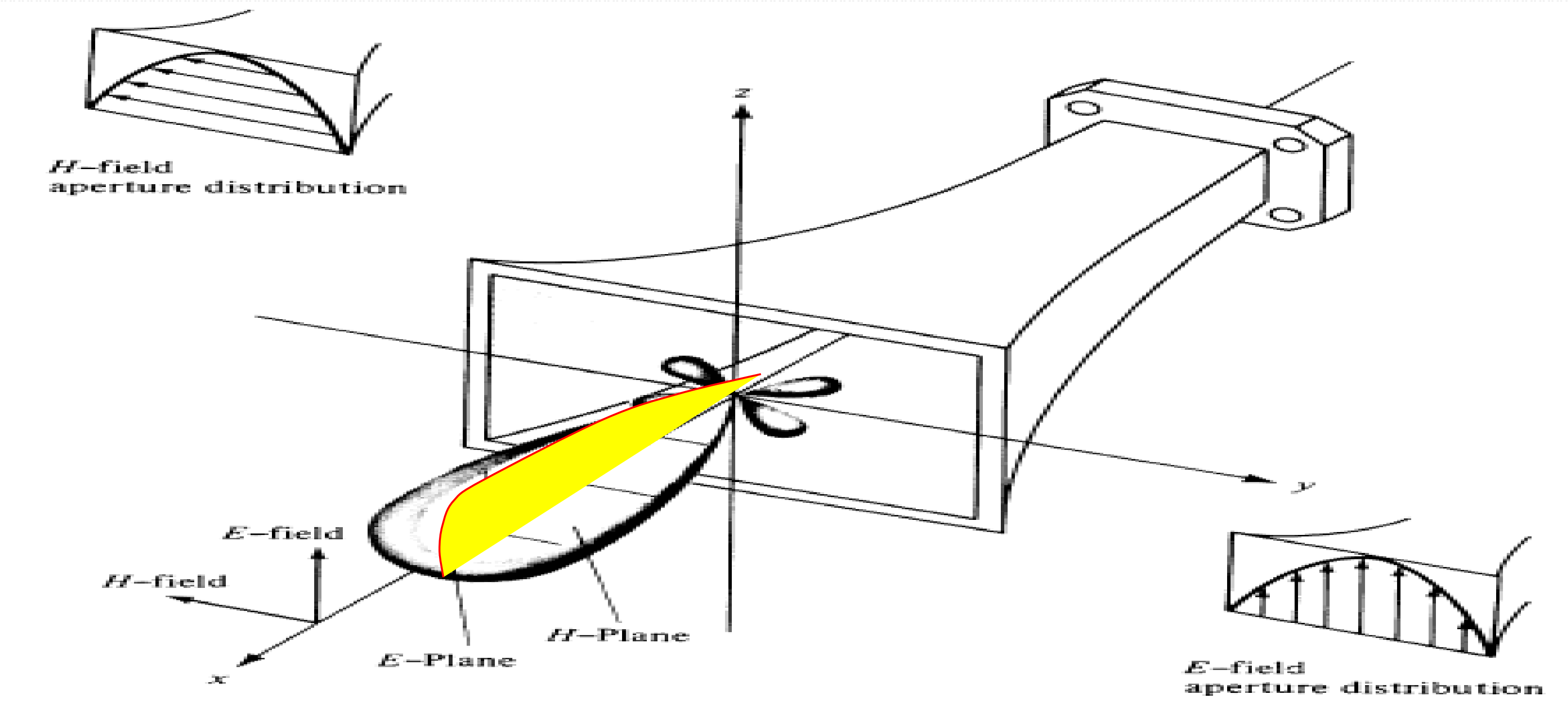
Principal Patterns

For linearly polarized antenna performance is often described in terms of its principal E-and H-Plane patterns

E- Plane : the plane containing the electric field vector and the maximum radiation

H- Plane : the plane containing the magnetic field vector and the maximum radiation

x-z elevation plane contain principal E- plane
x-y azimuthal plane contain principal H- plane



Principal E and H plane pattern for a pyramidal horn antenna

Field Regions

The space surrounding an antenna is usually subdivided into three regions:

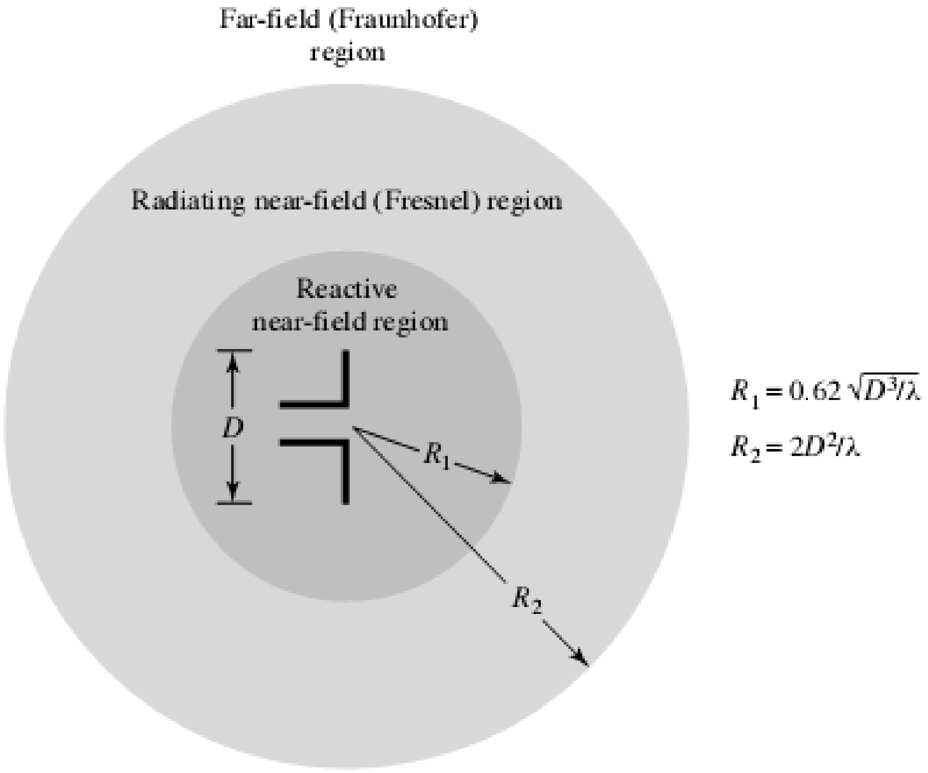


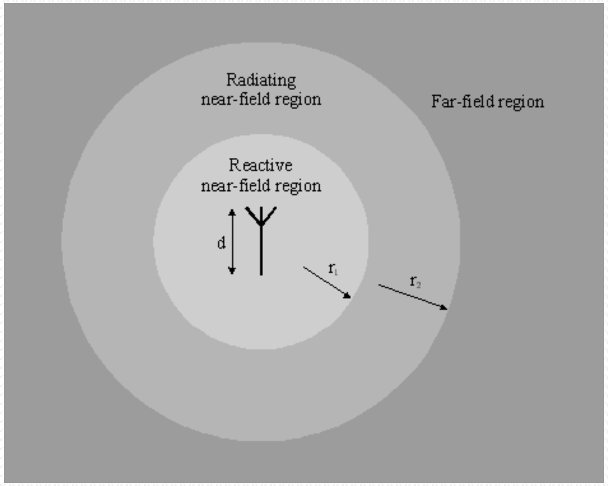
Figure 2.7 Field regions of an antenna.

Field Regions

The space surrounding an antenna is usually subdivided into three regions:

- **Reactive near-field region:** That portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates.
- **Radiating near-field (Fresnel) region:** That region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna
- **Far-field (Fraunhofer) region:** That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna.
-

$$r_1 \approx 0.62\sqrt{\frac{d^2}{\lambda}} \qquad r_2 \approx \frac{2d^2}{\lambda} \qquad \lambda = \frac{c_0}{f}$$



Field Regions

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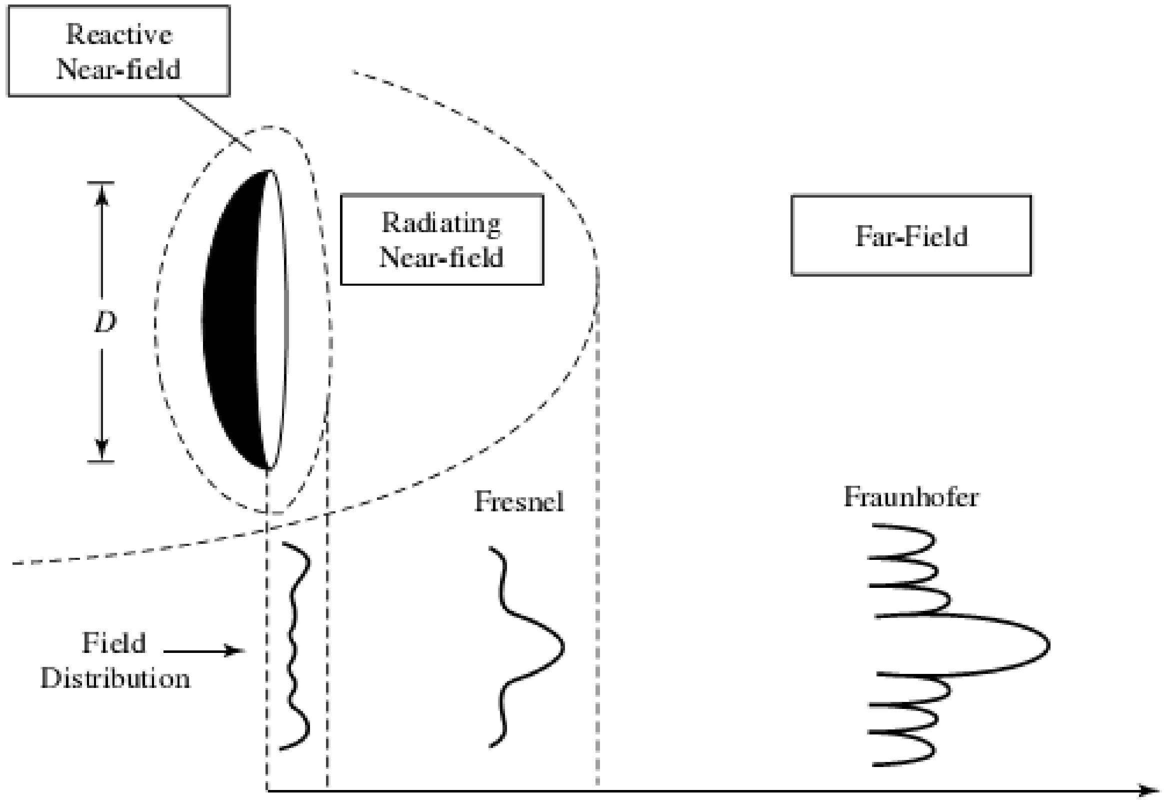

Figure 2.8 Typical changes of antenna amplitude pattern shape from reactive near field toward the far field. (SOURCE: Y. Rahmat-Samii, L. I. Williams, and R. G. Yoccarino, The UCLA Bi-polar Planar-Near-Field Antenna Measurement and Diagnostics Range," *IEEE Antennas & Propagation Magazine*, Vol. 37, No. 6, December 1995 © 1995 IEEE).

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Radiation Intensity

- Radiation intensity in a given direction is defined as "the power radiated from an antenna per unit solid angle."

- The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance.

$$U = r^2 W_{rad}$$

W_{rad} – radiation density (W/m^2)

r – distance (m)

U - radiation intensity (W/ unit solid angle)

Radiation Intensity

- The radiation intensity is also related to the far-zone electric field of an antenna, by

$$U(\theta,\phi) = \frac{r^2}{2\eta}|\mathbf{E}(r,\theta,\phi)|^2 \simeq \frac{r^2}{2\eta}\left[|E_\theta(r,\theta,\phi)|^2 + |E_\phi(r,\theta,\phi)|^2\right]$$
$$\simeq \frac{1}{2\eta}\left[|E_\theta^\circ(\theta,\phi)|^2 + |E_\phi^\circ(\theta,\phi)|^2\right] \tag{2-12a}$$

where

$\mathbf{E}(r,\theta,\phi)$ = far-zone electric-field intensity of the antenna $= \mathbf{E}^\circ(\theta,\phi)\dfrac{e^{-jkr}}{r}$

E_θ, E_ϕ = far-zone electric-field components of the antenna

η = intrinsic impedance of the medium

- The total power is obtained by integrating the radiation intensity, over the entire solid angle of 4п. Thus

$$P_{\text{rad}} = \oiint_{\Omega} U\,d\Omega = \int_0^{2\pi}\int_0^{\pi} U \sin\theta\,d\theta\,d\phi \tag{2-13}$$

where $d\Omega$ = element of solid angle $= \sin\theta\,d\theta\,d\phi$.

Radiation Intensity

- Radiation patterns may be functions of both spherical coordinate angles θ and Φ
- Let the radiation intensity of an antenna be of the form

$$U = B_0 F(\theta, \phi) \simeq \frac{1}{2\eta}\left[|E_\theta^0(\theta, \phi)|^2 + |E_\phi^0(\theta, \phi)|^2\right]$$

- The maximum value of radiation intensity

$$U_{\max} = B_0 F(\theta, \phi)|_{\max} = B_0 F_{\max}(\theta, \phi)$$

- The total radiated power is found using

$$P_{\text{rad}} = \oiint_{\Omega} U(\theta, \phi)\, d\Omega = B_0 \int_0^{2\pi} \int_0^{\pi} F(\theta, \phi) \sin\theta \, d\theta \, d\phi$$

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Directivity

Directivity (D):

- "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions"
- the directivity of a nonisotropic source is equal to the ratio of its radiation intensity in a given direction over that of isotropic source

$$D = \frac{U}{U_0}$$

- The average radiation intensity is equal to the total power radiated by the antenna divided by 4π.

$$\boxed{D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}}}$$

- If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as

$$\boxed{D_{\max} = D_0 = \frac{U|_{\max}}{U_0} = \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{\text{rad}}}}$$

U = radiation intensity (W/unit solid angle)

Umax = maximum radiation intensity (W/unit solid angle)

U_0= radiation intensity of isotropic source (W/unit solid angle)

P_{rad} = total radiated power (W)

D = directivity(dimensionless)

D_0= maximumdirectivity(dimensionless)

Directivity

The general expression for the directivity and maximum directivity (D_0) using

$$D(\theta,\phi) = 4\pi \frac{F(\theta,\phi)}{\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

$$D_0 = 4\pi \frac{F(\theta,\phi)|_{\max}}{\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

$$D_0 = \frac{4\pi}{\left[\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi\right] \Big/ F(\theta,\phi)|_{\max}} = \frac{4\pi}{\Omega_A}$$

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}}$$

$$U = B_0 F(\theta,\phi) \simeq \frac{1}{2\eta}\left[|E_\theta^0(\theta,\phi)|^2 + |E_\phi^0(\theta,\phi)|^2\right]$$

$$P_{\text{rad}} = \oiint_\Omega U(\theta,\phi)\, d\Omega = B_0 \int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi$$

$$D_{\max} = D_0 = \frac{U|_{\max}}{U_0} = \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{\text{rad}}}$$

where Ω_A is the beam solid angle, and it is given by

$$\Omega_A = \frac{1}{F(\theta,\phi)|_{\max}}\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi = \int_0^{2\pi}\int_0^{\pi} F_n(\theta,\phi)\sin\theta\, d\theta\, d\phi \tag{2-24}$$

$$F_n(\theta,\phi) = \frac{F(\theta,\phi)}{F(\theta,\phi)|_{\max}} \tag{2-25}$$

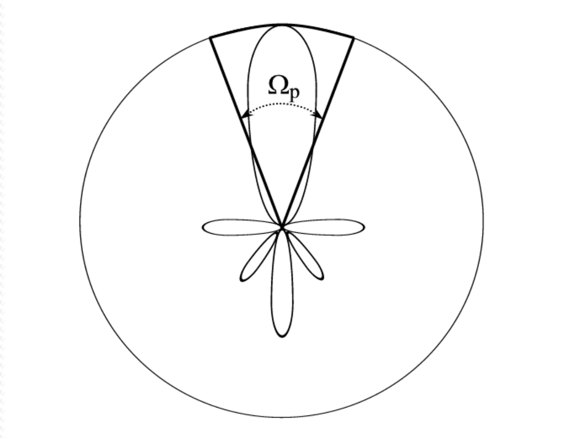
Dividing by $F(\theta,\phi)|_{\max}$ merely normalizes the radiation intensity $F(\theta,\phi)$, and it makes its maximum value unity.

Directivity

Directive gain

The *directive gain*,, of an antenna is the ratio of the normalized power in a particular direction to the average normalized power, or

$$D(\theta,\phi)=\frac{P_n(\theta,\phi)}{P_n(\theta,\phi)_{avg}}$$



Where the normalized power's average value taken over the entire spherical solid angle is

$$P_n(\theta,\phi)_{avg}=\frac{\iint P_n(\theta,\phi)\,d\Omega}{\iint d\Omega}=\frac{\Omega_p}{4\pi}$$

The *directivity, Dmax*, is the maximum directive gain,

$$D_{\max}=D(\theta,\phi)_{\max}=\frac{P_n(\theta,\phi)_{\max}}{P_n(\theta,\phi)_{avg}}$$

$$\boxed{D_{\max}=\frac{4\pi}{\Omega_p}}$$

Using $P_n(\theta,\phi)_{\max}=1$

Directivity

Partial Directivity of antenna:

Partial directivity of an antenna for a given polarization in a given direction as

→" that part of the radiation intensity corresponding to a given polarization divided by the total radiation intensity averaged over all directions."

With this definition for the partial directivity, then in a given direction

→"the total directivity is the sum of the partial directivities for any two orthogonal polarizations

For a spherical coordinate system, the total maximum directivity D_0 for the orthogonal θ and Φ components of an antenna can be written as

$$D_0 = D_\theta + D_\phi$$

While the partial directivities D_θ and D_Φ are expressed as

$$D_\theta = \frac{4\pi U_\theta}{(P_{\text{rad}})_\theta + (P_{\text{rad}})_\phi}$$

$$D_\phi = \frac{4\pi U_\phi}{(P_{\text{rad}})_\theta + (P_{\text{rad}})_\phi}$$

where

U_θ = radiation intensity in a given direction contained in θ field component

U_ϕ = radiation intensity in a given direction contained in ϕ field component

$(P_{\text{rad}})_\theta$ = radiated power in all directions contained in θ field component

$(P_{\text{rad}})_\phi$ = radiated power in all directions contained in ϕ field component

Directivity

Directional Patterns:

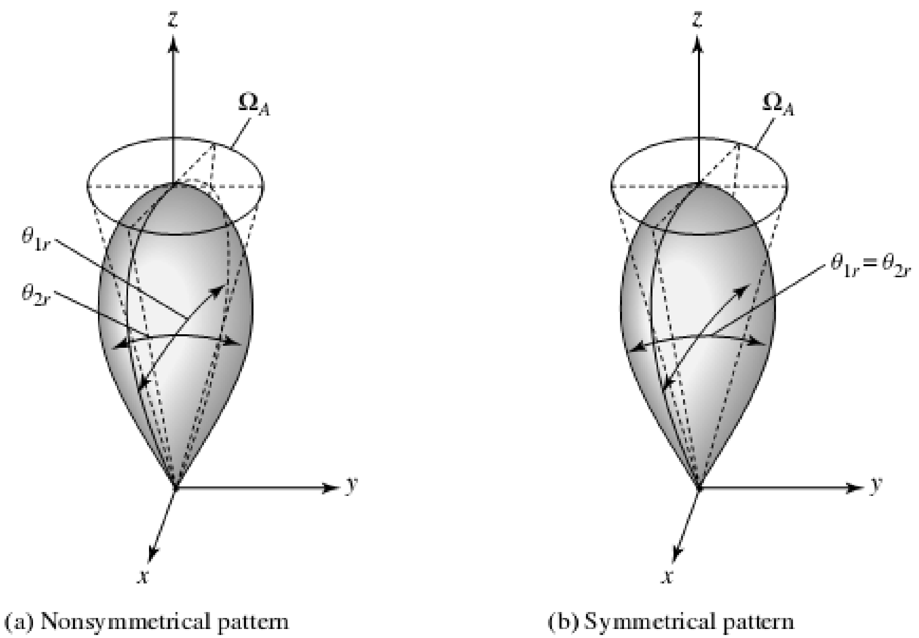


Figure 2.14 Beam solid angles for nonsymmetrical and symmetrical radiation patterns.

In Figure2.14(a). For a rotationally symmetric pattern, the half-power beam widths in any two perpendicular planes are the same, as illustrated in Figure2.14(b).

With this approximation, maximum directivity can be approximated by

$$\boxed{D_0 = \frac{4\pi}{\Omega_A} \simeq \frac{4\pi}{\Theta_{1r}\Theta_{2r}}}$$

Directivity

Directional Patterns:

With this approximation, maximum directivity can be approximated by

$$\boxed{D_0 = \frac{4\pi}{\Omega_A} \simeq \frac{4\pi}{\Theta_{1r}\Theta_{2r}}}$$

The beam solid angle Ω_A has been approximated by

$$\boxed{\Omega_A \simeq \Theta_{1r}\Theta_{2r}} \tag{2-26a}$$

where

Θ_{1r} = half-power beamwidth in one plane (rad)
Θ_{2r} = half-power beamwidth in a plane at a right angle to the other (rad)

If the beamwidths are known in degrees, (2-26) can be written as

$$D_0 \simeq \frac{4\pi(180/\pi)^2}{\Theta_{1d}\Theta_{2d}} = \frac{41{,}253}{\Theta_{1d}\Theta_{2d}} \tag{2-27}$$

where

Θ_{1d} = half-power beamwidth in one plane (degrees)
Θ_{2d} = half-power beamwidth in a plane at a right angle to the other (degrees)

For planar arrays, a better approximation to (2-27) is [9]

$$\boxed{D_0 \simeq \frac{32{,}400}{\Omega_A(\text{degrees})^2} = \frac{32{,}400}{\Theta_{1d}\Theta_{2d}}} \tag{2-27a}$$

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Antenna Gain

- The ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically

- The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted (input) by the antenna divided by 4 π

- In equation form this can be expressed as

$$\text{Gain} = 4\pi \frac{\text{radiation intensity}}{\text{total input (accepted) power}} = 4\pi \frac{U(\theta, \phi)}{P_{in}} \quad \text{(dimensionless)}$$

Antenna Gain

"the ratio of the Power gain in a given direction to the power gain of a reference antenna in its referenced direction"

The power input must be the same for both antennas

Mostly Reference antenna is a lossless isotropic source. Thus

$$G = \frac{4\pi U(\theta, \phi)}{P_{in}\,(\text{lossless isotropic source})} \quad \text{(dimensionless)}$$

When the direction is not stated, the power gain is usually taken in the direction of maximum radiation.

We can write that the total radiated power related to the total input power

$$P_{\text{rad}} = e_{cd} P_{in}$$

where e_{cd} is the antenna radiation efficiency

Antenna Gain

$$G(\theta,\phi) = e_{cd}\left[4\pi \frac{U(\theta,\phi)}{P_{\text{rad}}}\right] \tag{2-48}$$

which is related to the directivity of (2-16) and (2-21) by

$$\boxed{G(\theta,\phi) = e_{cd} D(\theta,\phi)} \tag{2-49}$$

In a similar manner, the maximum value of the gain is related to the maximum directivity of (2-16a) and (2-23) by

$$\boxed{G_0 = G(\theta,\phi)|_{\max} = e_{cd} D(\theta,\phi)|_{\max} = e_{cd} D_0} \tag{2-49a}$$

$$\boxed{\begin{aligned} G_{abs}(\theta,\phi) &= e_r G(\theta,\phi) = (1-|\Gamma|^2)G(\theta,\phi) \\ &= e_r e_{cd} D(\theta,\phi) = e_o D(\theta,\phi) \end{aligned}}$$

$$\boxed{\begin{aligned} G_{0abs} &= G_{abs}(\theta,\phi)|_{\max} = e_r G(\theta,\phi)|_{\max} = (1-|\Gamma|^2)G(\theta,\phi)|_{\max} \\ &= e_r e_{cd} D(\theta,\phi)|_{\max} = e_o D(\theta,\phi)|_{\max} = e_o D_0 \end{aligned}}$$

Antenna Gain

Partial gain of an antenna

For a given polarization in a given direction

Total gain

$$G_0 = G_\theta + G_\phi \tag{2-50}$$

while the partial gains G_θ and G_ϕ are expressed as

$$G_\theta = \frac{4\pi U_\theta}{P_{in}} \tag{2-50a}$$

$$G_\phi = \frac{4\pi U_\phi}{P_{in}} \tag{2-50b}$$

where

U_θ = radiation intensity in a given direction contained in E_θ field component
U_ϕ = radiation intensity in a given direction contained in E_ϕ field component
P_{in} = total input (accepted) power

Antenna Gain

- Relationship between antenna gain and effective area

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

  - G = antenna gain
  - A_e = effective area
  - f = carrier frequency
  - c = speed of light (3×10^8 m/s)
  - λ = carrier wavelength

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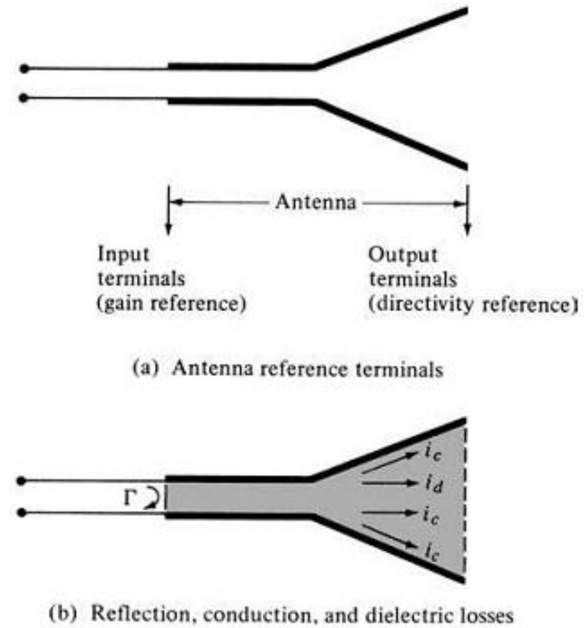
Antenna Efficiency

In general, the over all Efficiency can be written as

$$\boxed{e_0 = e_r e_c e_d} \tag{2-44}$$

where

e_0 = total efficiency (dimensionless)
e_r = reflection (mismatch) efficiency $= (1 - |\Gamma|^2)$ (dimensionless)
e_c = conduction efficiency (dimensionless)
e_d = dielectric efficiency (dimensionless)
Γ = voltage reflection coefficient at the input terminals of the antenna $[\Gamma = (Z_{in} - Z_0)/(Z_{in} + Z_0)$ where Z_{in} = antenna input impedance, Z_0 = characteristic impedance of the transmission line]
VSWR = voltage standing wave ratio $= \dfrac{1 + |\Gamma|}{1 - |\Gamma|}$



ure 2.22 Reference terminals and losses of an antenna.

Usually e_c and e_d are very difficult to compute, but they can be determined experimentally. Even by measurements they cannot be separated, and it is usually more convenient to write (2-44) as

$$e_0 = e_r e_{cd} = e_{cd}(1 - |\Gamma|^2) \tag{2-45}$$

where $e_{cd} = e_c e_d$ = antenna radiation efficiency, which is used to relate the gain and directivity.

Radiation Resistance & Antenna Efficiency

- Radiation resistance (R_{rad}) is a fictitious resistance, such that the average power flow out of the antenna is

$$P_{av} = (1/2)\, I^2\, R_{rad}$$

- Using the equations for our short (Hertzian) dipole we find that

$$R_{rad} = 80\, \pi^2\, (l/\lambda)^2 \text{ ohms}$$

- Antenna Efficiency

$$\varepsilon_o = R_{rad}/(R_{rad} + R_{loss})$$

where R_{loss} →ohmic losses as heat

- Gain = ε_ox Directivity

$$G = \varepsilon_o\, D$$

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Beamwidth

- **Half-power beamwidth** (HPBW) (θ_H)

  is the angle between two vectors from the pattern's origin to the points of the major lobe where the radiation intensity is half its maximum

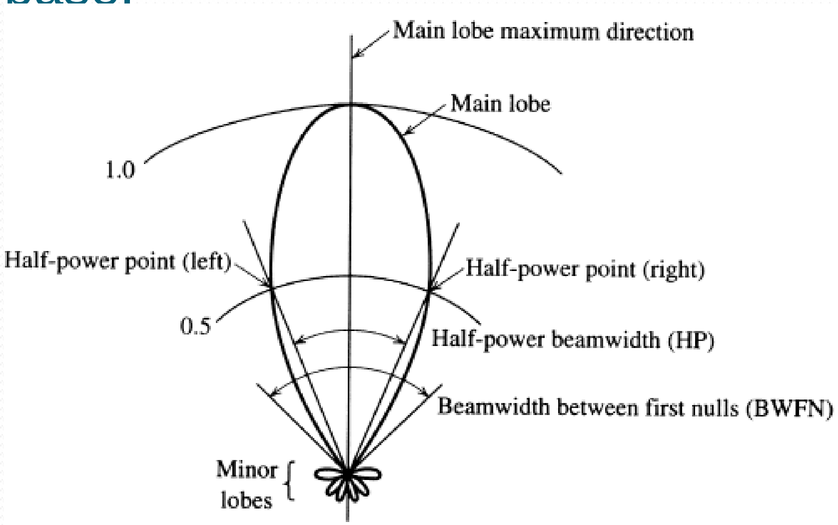
  - Often used to describe the antenna resolution properties
    - Important in radar technology, radioastronomy, etc.

    Power pattern of $U(\theta) = \cos^2(\theta)\cos^2(3\theta)$.

- **First-null beamwidth** (FNBW) (θ_N)

  is the angle between two vectors, originating at the pattern's origin and tangent to the main beam at its base.

    - Often FNBW ≈ 2*HPBW



Beam efficiency

- To judge the quality of transmitting and receiving antennas

$$\text{BE} = \frac{\text{power transmitted (received) within cone angle } \theta_1}{\text{power transmitted (received) by the antenna}} \text{(dimensionless)} \quad (2\text{-}53)$$

where θ_1 is the half-angle of the cone within which the percentage of the total power is to be found. Equation (2-53) can be written as

$$\text{BE} = \frac{\int_0^{2\pi} \int_0^{\theta_1} U(\theta, \phi) \sin\theta \, d\theta \, d\phi}{\int_0^{2\pi} \int_0^{\pi} U(\theta, \phi) \sin\theta \, d\theta \, d\phi} \quad (2\text{-}54)$$

- If θ_1 is chosen as the angle where the first null or minimum occurs, then the beam efficiency will indicate the amount of power in the major lobe compared to the total power.

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Bandwidth

- **Bandwidth:** the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard
- For broadband antennas, the bandwidth is usually expressed as the ratio of the upper-to-lower frequencies of acceptable operation
  - F.E. 10:1 bandwidth indicates that the upper frequency is 10 times greater than the lower
- For narrowband antennas, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the center frequency of the bandwidth
  - F.E. a 5% bandwidth indicates that the frequency difference of acceptable operation is 5% of the center frequency of the bandwidth

gain, side lobe level, beamwidth, polarization, and beam direction	⟷	*Pattern bandwidth*	input impedance and radiation efficiency	⟷	Impedance bandwidth

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Polarization

Polarization of an antenna:

- The polarization of the wave transmitted (radiated) by the antenna
- When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain
- Polarization of the radiated energy varies with the direction from the center of the antenna, so that different parts of the pattern may have different polarizations
- Polarization may be classified as linear, circular, or elliptical

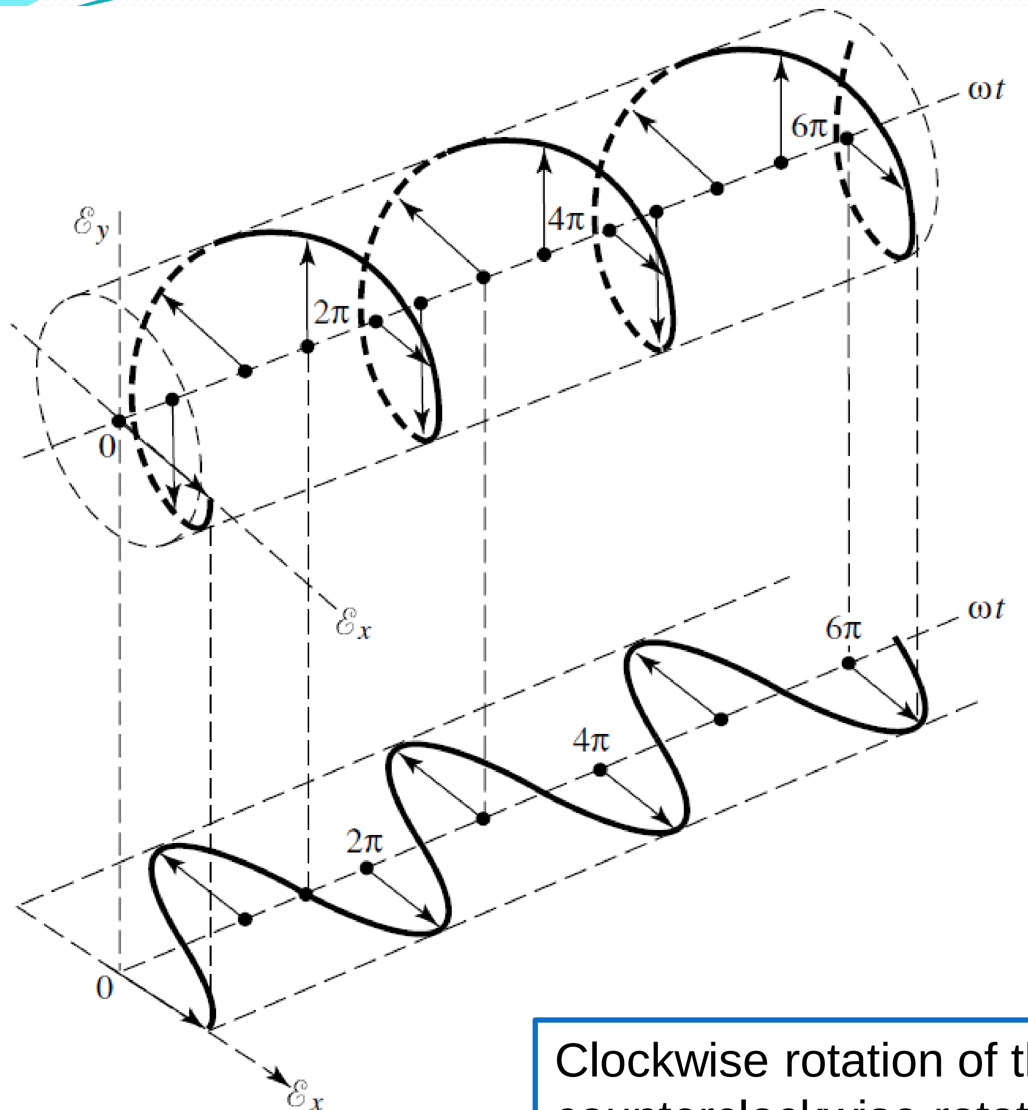
Polarization

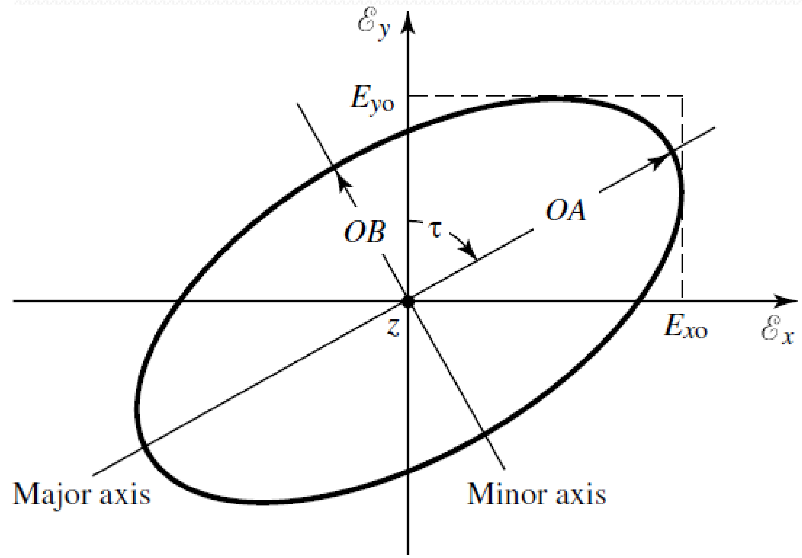
Polarization of a radiated wave

- is defined as " that property of an electro magnetic wave describing the time varying direction and relative magnitude of the electric-field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation."

- Polarization then is the curve traced by the end point of the arrow (vector) representing the instantaneous electric field. The field must be observed along the direction of propagation. A typical trace as a function of time is shown in Figure

Polarization of EM Waves

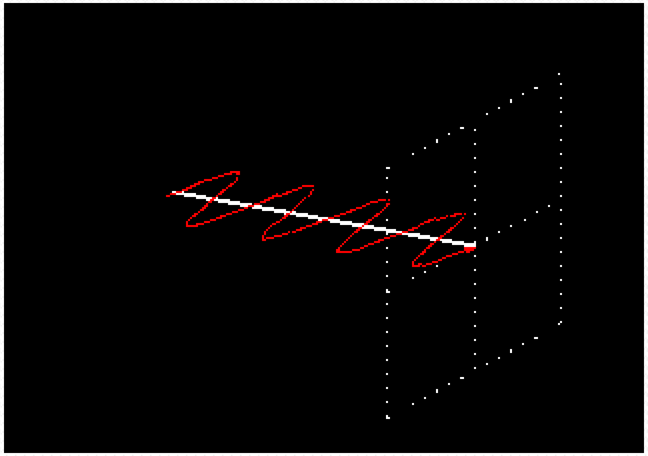




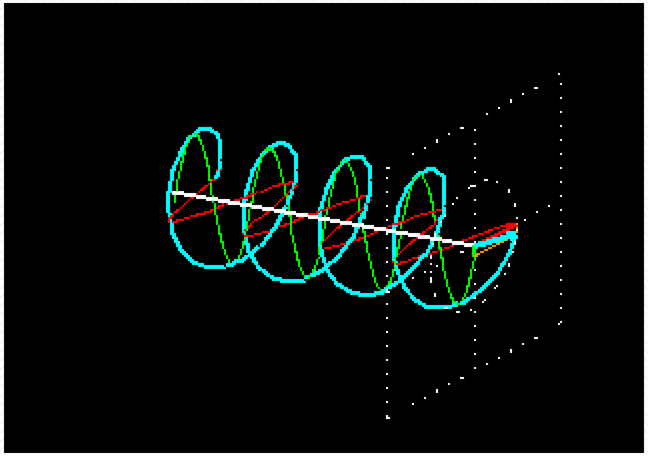
(b) Polarization ellipse

Clockwise rotation of the **E** vector= right-hand polarization
counterclockwise rotation of the **E** vector = left-hand polarization

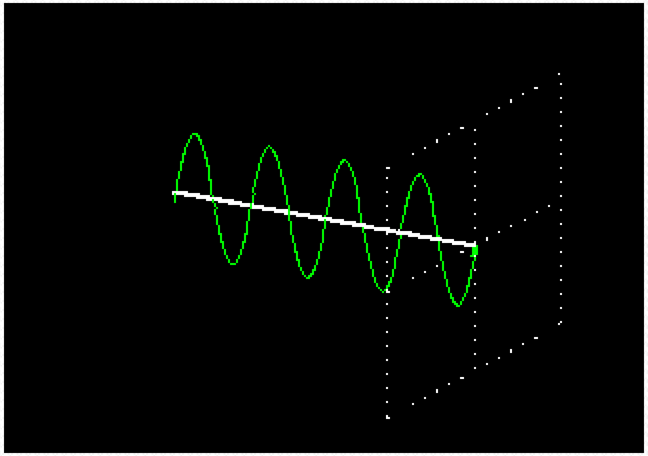
Polarization of EM Waves



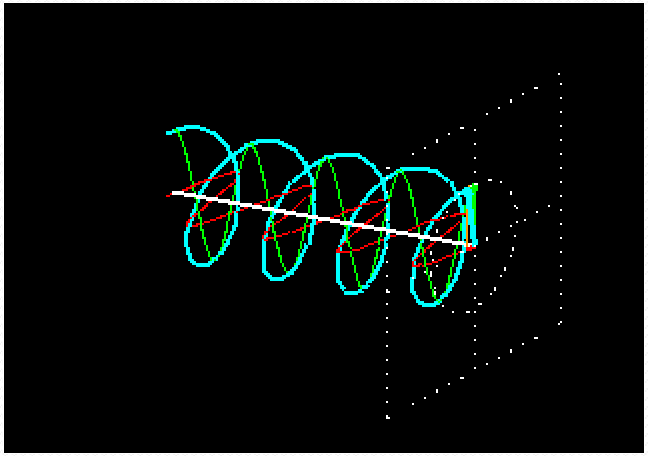
Horizontal polarization



Circular polarization (LCP)

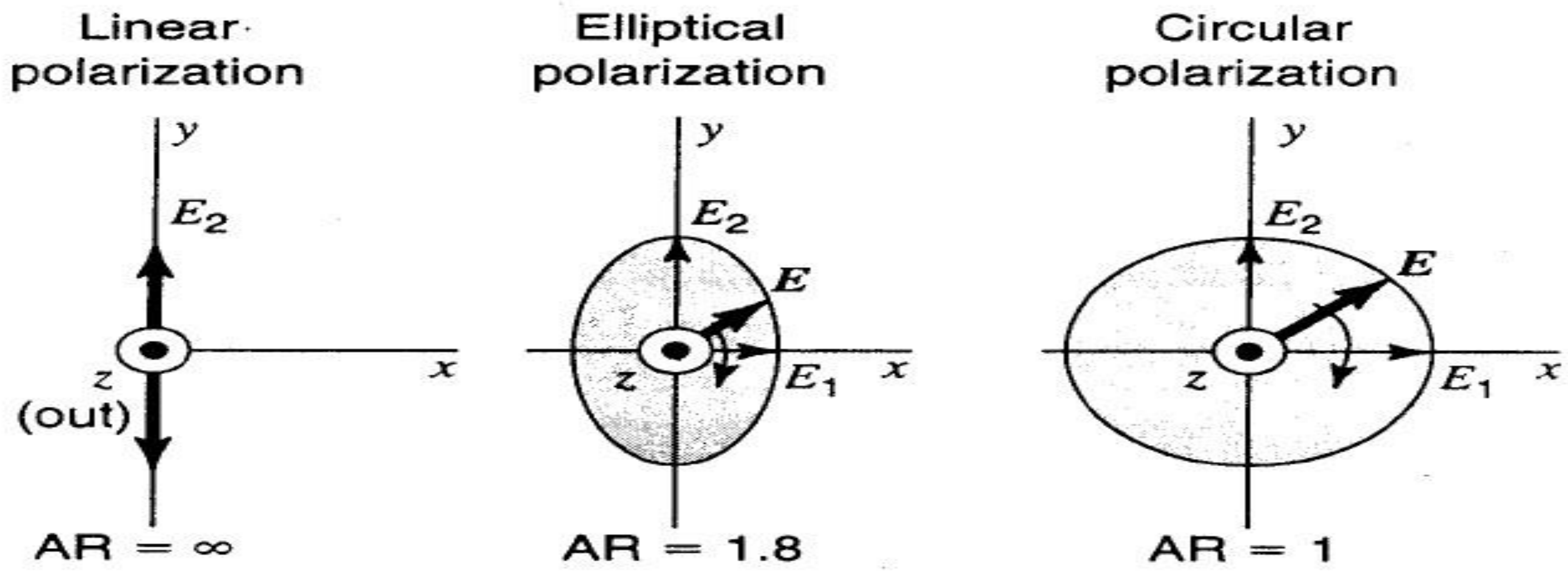


Vertical polarization



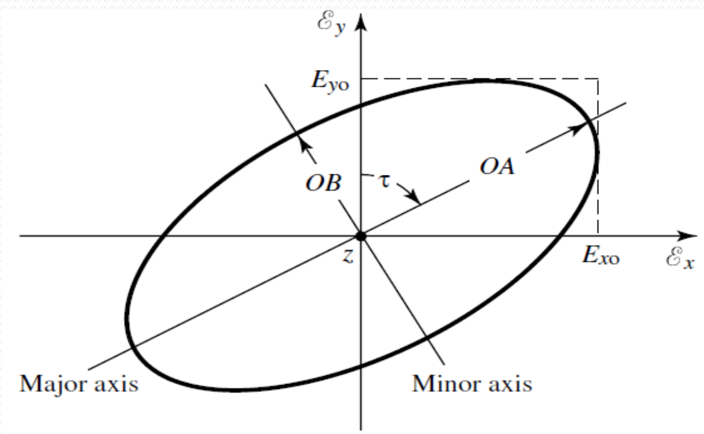
Circular polarization (RCP)

Polarization of EM Waves



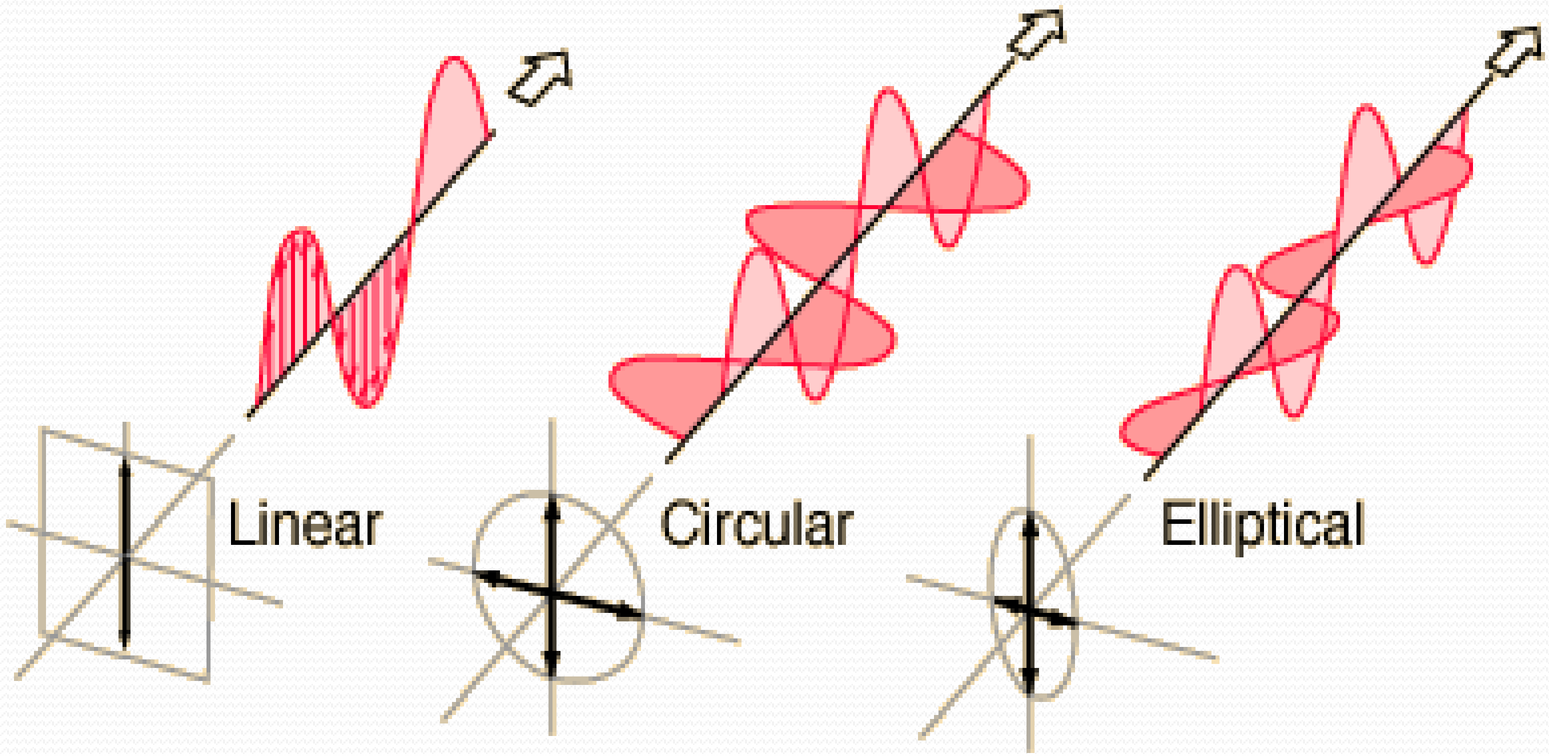
AR: The ratio of the major axis to the minor axis is referred to as the axial ratio (AR) ,and it is equal to

$$AR = \frac{\text{major axis}}{\text{minor axis}} = \frac{OA}{OB}, \quad 1 \leq AR \leq \infty$$



(b) Polarization ellipse

Polarization Electromagnetic wave



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Polarization of EM Waves

- The instantaneous field of a plane wave, traveling in the negative *z direction:*

$$\mathscr{E}(z;t) = \hat{\mathbf{a}}_x \mathscr{E}_x(z;t) + \hat{\mathbf{a}}_y \mathscr{E}_y(z;t)$$

- Instantaneous components are related to their complex counterparts by

$$\mathscr{E}_x(z;t) = \mathrm{Re}[E_x^- e^{j(\omega t + kz)}] = \mathrm{Re}[E_{xo} e^{j(\omega t + kz + \phi_x)}]$$
$$= E_{xo} \cos(\omega t + kz + \phi_x)$$
$$\mathscr{E}_y(z;t) = \mathrm{Re}[E_y^- e^{j(\omega t + kz)}] = \mathrm{Re}[E_{yo} e^{j(\omega t + kz + \phi_y)}]$$
$$= E_{yo} \cos(\omega t + kz + \phi_y)$$

where E_{xo} *and* E_{yo} *are, respectively, the maximum magnitudes of the x and y components.*

Linear Polarization:

- A time-harmonic wave is linearly polarized at a given point in space if the electric-field (or magnetic-field) vector at that point is always oriented along the same straight line at every instant of time.

- This is accomplished if the field vector (electric or magnetic) possesses:
  - Only one component, or
  - Two orthogonal linear components that are in time phase or 180◦ (or multiples of 180◦) out-of-phase.

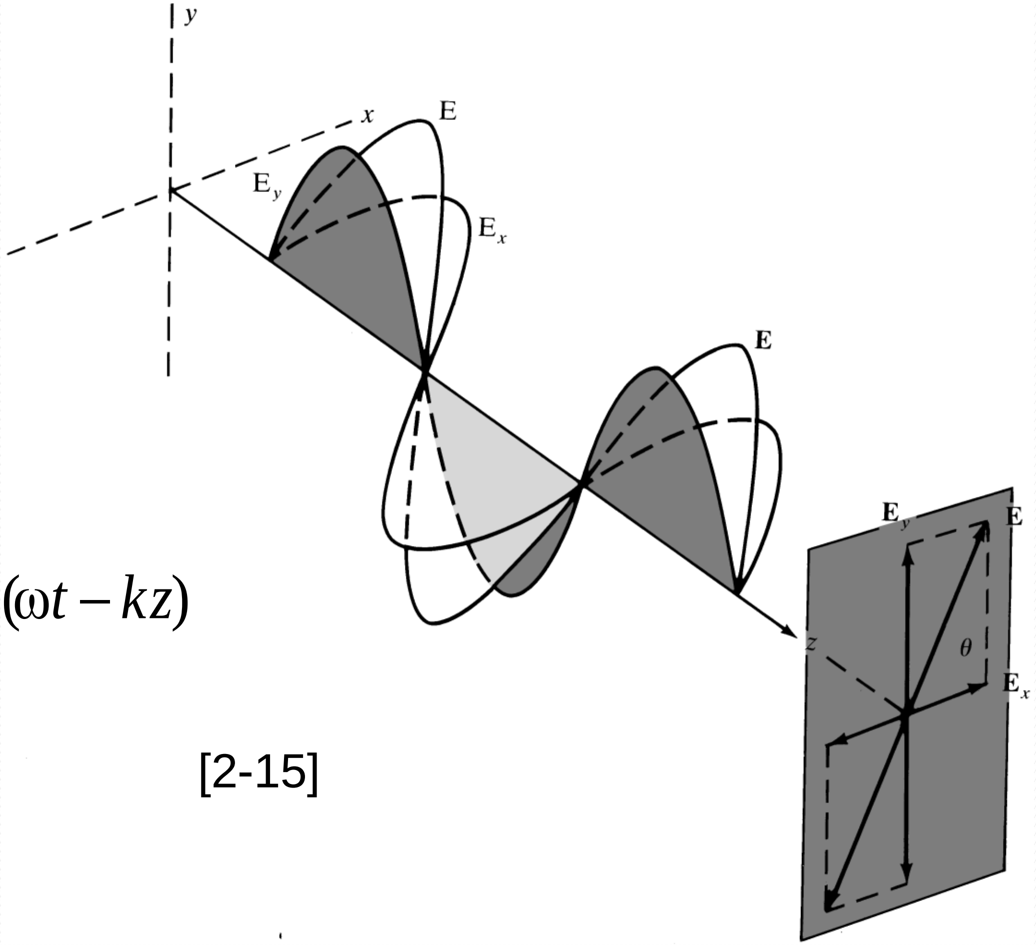
- the time-phase difference between the two components must be

$$\Delta\phi = \phi_y - \phi_x = n\pi, \quad n = 0, 1, 2, 3, \ldots$$

linearly polarized plane waves

•Any two orthogonal plane waves Can be combined into a linearly Polarized wave.

•Conversely, any arbitrary linearly polarized wave can be resolved into two independent Orthogonal plane waves that are in phase.



$$\vec{E} = e_x E_{0x} \cos(\omega t - kz) + e_y E_{0y} \cos(\omega t - kz)$$

$$E = \left|\vec{E}\right| = \sqrt{E_{0x}{}^2 + E_{0y}{}^2}$$

$$\theta = \tan^{-1}\left(\frac{E_{0y}}{E_{0x}}\right)$$

[2-15]

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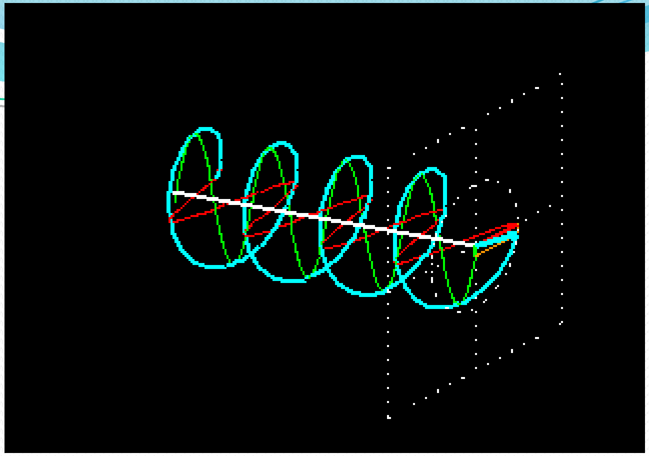
Circular Polarization:

- A time-harmonic wave is circularly polarized at a given point in space if the Electric (or magnetic) field vector at that point traces a circle as a function of time

- The necessary and sufficient conditions to accomplish this are if the field vector (electric or magnetic) possesses all of the following:

  - a. The field must have two orthogonal linear components, and
  - b. The two components must have the same magnitude, and
  - c. The two components must have a time-phase difference of odd multiples of 90°.

Circular Polarization:



- **Circular Polarization:**
  - magnitudes of the two components are same
  - the time-phase difference between components is odd multiples of π/2

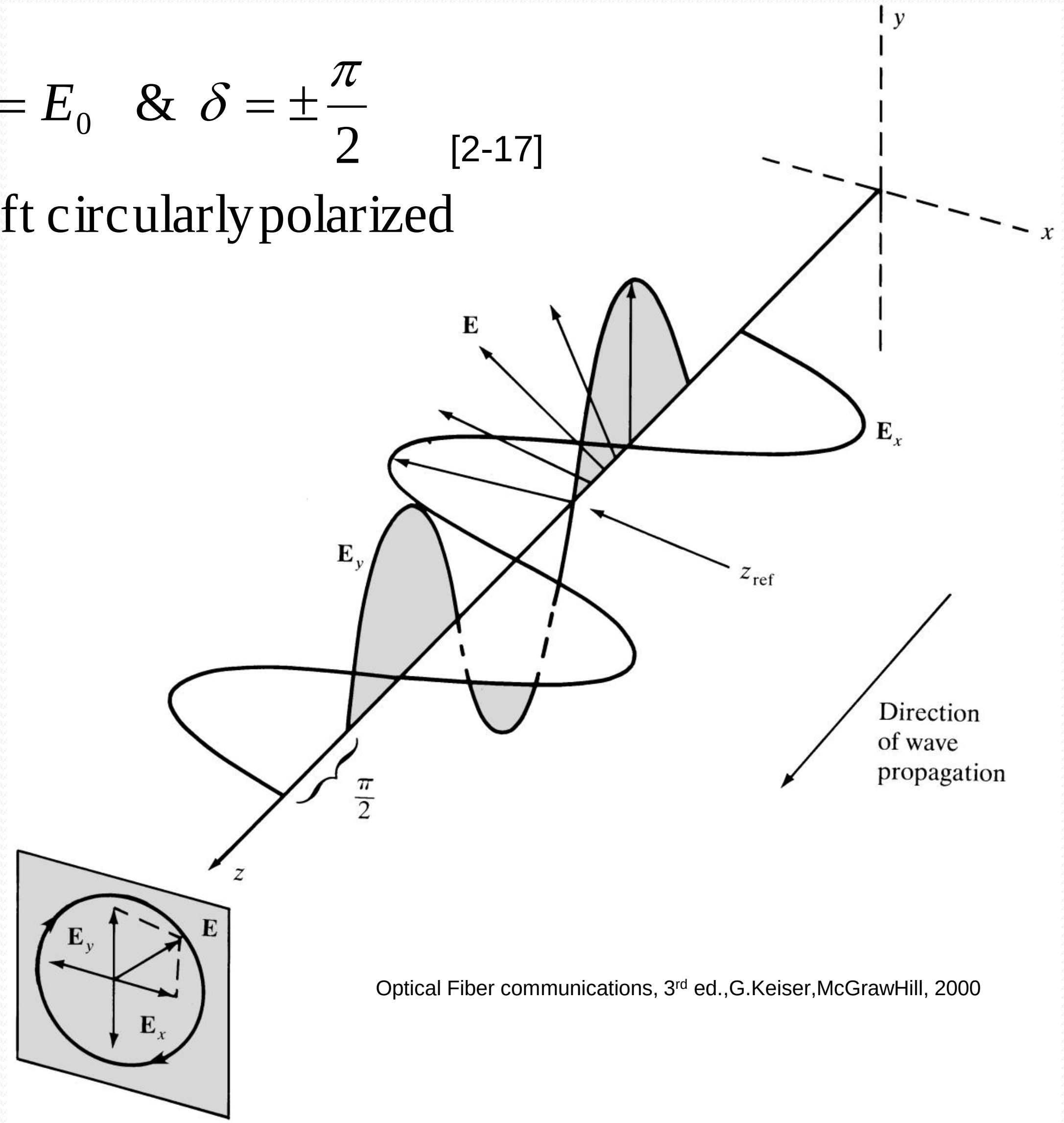
$$|\mathscr{E}_x| = |\mathscr{E}_y| \Rightarrow E_{xo} = E_{yo}$$

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} +\left(\frac{1}{2} + 2n\right)\pi, n = 0, 1, 2, \ldots & \text{for CW} \\ -\left(\frac{1}{2} + 2n\right)\pi, n = 0, 1, 2, \ldots & \text{for CCW} \end{cases}$$

Circular Polarized wave:

$$\text{Circular polarization}: E_{0x} = E_{0y} = E_0 \quad \& \quad \delta = \pm\frac{\pi}{2} \qquad \text{[2-17]}$$

$+$: right circularly polarized, $-$: left circularly polarized



Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

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Elliptical Polarization:

- A time-harmonic wave is elliptically polarized if the tip of the field vector (electric or magnetic) traces an elliptical locus in space.

- At various instants of time the field vector changes continuously with time at such a manner as to describe an elliptical locus.

- It is right-hand (clockwise) elliptically polarized if the field vector rotates clockwise, and it is left-hand (counterclockwise) elliptically polarized if the field vector of the ellipse rotates counterclockwise

Elliptical Polarization:

The necessary and sufficient conditions

- The field must have two orthogonal linear components, and

- The two components can be of the same or different magnitude

- (1) If the two components are not of the same magnitude, the time-phase difference between the two components must not be 0 or multiples of 180 (because it will then be linear).

- (2)If the two components are of the same magnitude, the time-phase difference between the two components must not be odd multiples of 90 (because it will then be circular).

Elliptical Polarization:

- magnitudes of the two components are NOT same the time-phase difference between components is odd multiples of π/2
- Or when the time phase difference between the two components is not equal to multiples of π/2 (irrespective of their magnitudes)

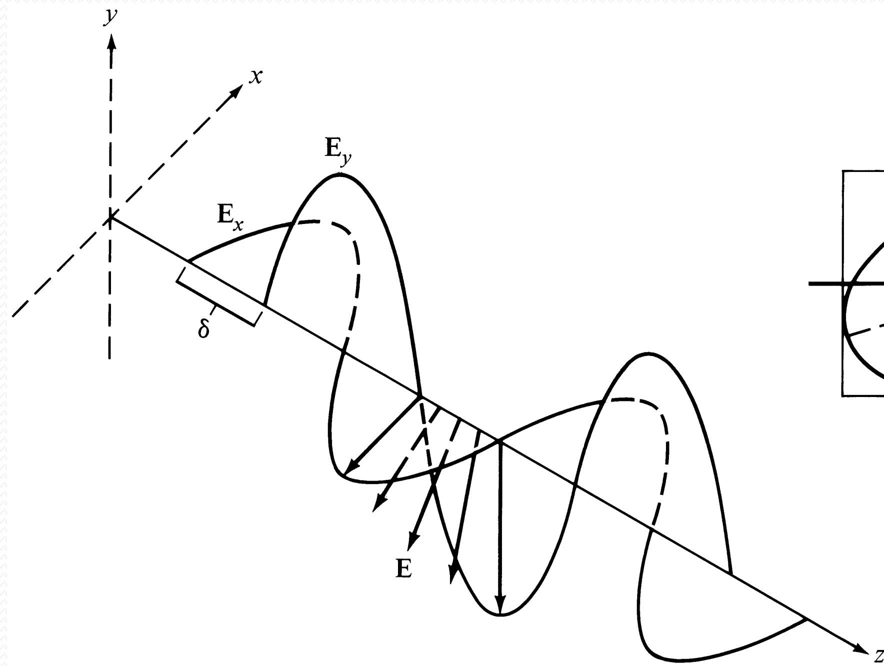
$$|\mathscr{E}_x| \neq |\mathscr{E}_y| \Rightarrow E_{xo} \neq E_{yo}$$

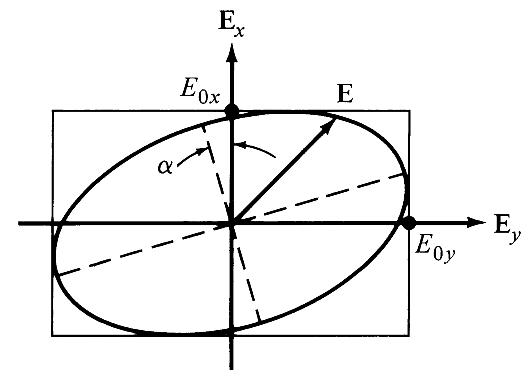
$$\text{when } \Delta\phi = \phi_y - \phi_x = \begin{cases} +(\frac{1}{2} + 2n)\pi & \text{for CW} \\ -(\frac{1}{2} + 2n)\pi & \text{for CCW} \end{cases} \quad n = 0, 1, 2, \ldots$$

or

$$\Delta\phi = \phi_y - \phi_x \neq \pm\frac{n}{2}\pi = \begin{cases} > 0 & \text{for CW} \\ < 0 & \text{for CCW} \end{cases} \quad n = 0, 1, 2, 3, \ldots$$

Elliptically Polarized plane waves





$$\vec{E} = \mathrm{e}_x E_x + \mathrm{e}_y \mathrm{E}_y$$

$$= \mathrm{e}_x E_{0x} \cos(\omega t - kz) + \mathrm{e}_y \cos(\omega t - kz + \delta)$$

$$\left(\frac{E_x}{E_{0x}}\right)^2 + \left(\frac{E_y}{E_{0y}}\right)^2 - 2\left(\frac{E_x}{E_{0x}}\right)\left(\frac{E_y}{E_{0y}}\right)\cos\delta = \sin^2\delta \qquad [2\text{-}16]$$

$$\tan(2\alpha) = \frac{2E_{0x}E_{0y}\cos\delta}{E_{0x}{}^2 - E_{0y}{}^2}$$

Fundamental Parameters of Antennas

- Introduction
- Radiation Pattern
- Radiation Power Density
- Radiation intensity
- Directivity, Gain, Antenna efficiency, Beamwidth
- Bandwidth
- Linear, circular, and elliptical polarization
- Polarization loss factor and efficiency
- Antenna Input Impedance
- Elementary idea about self and mutual impedance
- Radiation efficiency
- Effective aperture, Antenna Temperature

Polarization Loss Factor & Efficiency

- Usually, polarization of the receiving antenna ≠ polarization of the incoming (incident) wave

  "polarization mismatch."

- The amount of power extracted by the antenna from the incoming signal will not be maximum because of the polarization loss

- Assuming that the electric field of the incoming wave can be written as

$$\mathbf{E}_i = \hat{\boldsymbol{\rho}}_w E_i$$

unit vector of the wave

Polarization Loss Factor & Efficiency

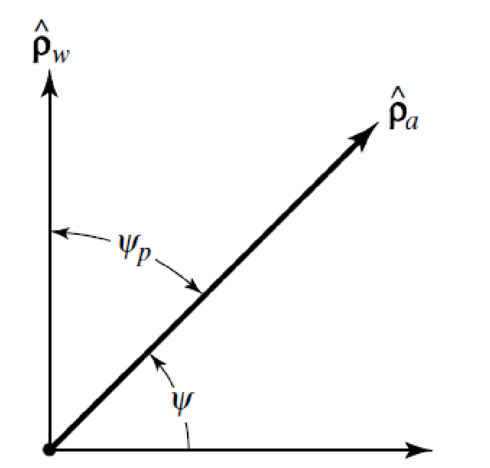
- Polarization of the electric field of the receiving antenna

$$\mathbf{E}_a = \hat{\boldsymbol{\rho}}_a E_a$$

- Polarization loss factor (PLF)

$$\text{PLF} = |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 = |\cos\psi_p|^2 \ \text{(dimensionless)}$$

angle between the two unit vectors



Polarization Loss Factor & Efficiency

Polarization efficiency

= Polarization mismatch = loss factor :

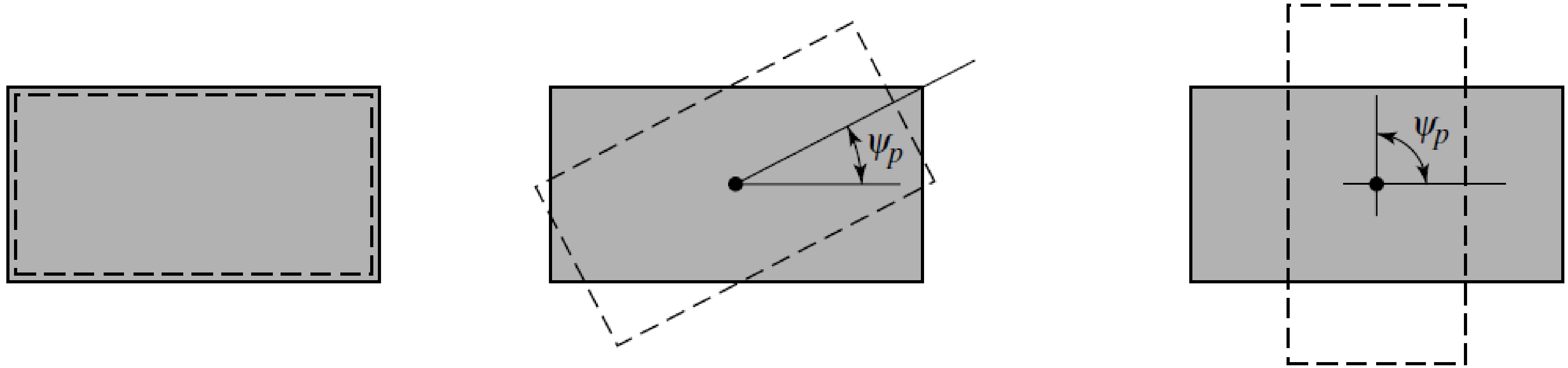
" the ratio of the power received by an antenna from a given plane wave of arbitrary polarization to the power that would be received by the same antenna from a plane wave of the same power flux density and direction of propagation, whose state of polarization has been adjusted for a maximum received power

$$p_e = \frac{|\boldsymbol{\ell}_{\mathbf{e}} \cdot \mathbf{E}^{\mathrm{inc}}|^2}{|\boldsymbol{\ell}_{\mathbf{e}}|^2 |\mathbf{E}^{\mathrm{inc}}|^2}$$

$$\begin{aligned} \boldsymbol{\ell}_e &= \text{vector effective length of the antenna} \\ \mathbf{E}^{\mathrm{inc}} &= \text{incident electric field} \end{aligned}$$

Polarization Loss Factor & Efficiency (Cont…)

- PLF for transmitting and receiving aperture antennas



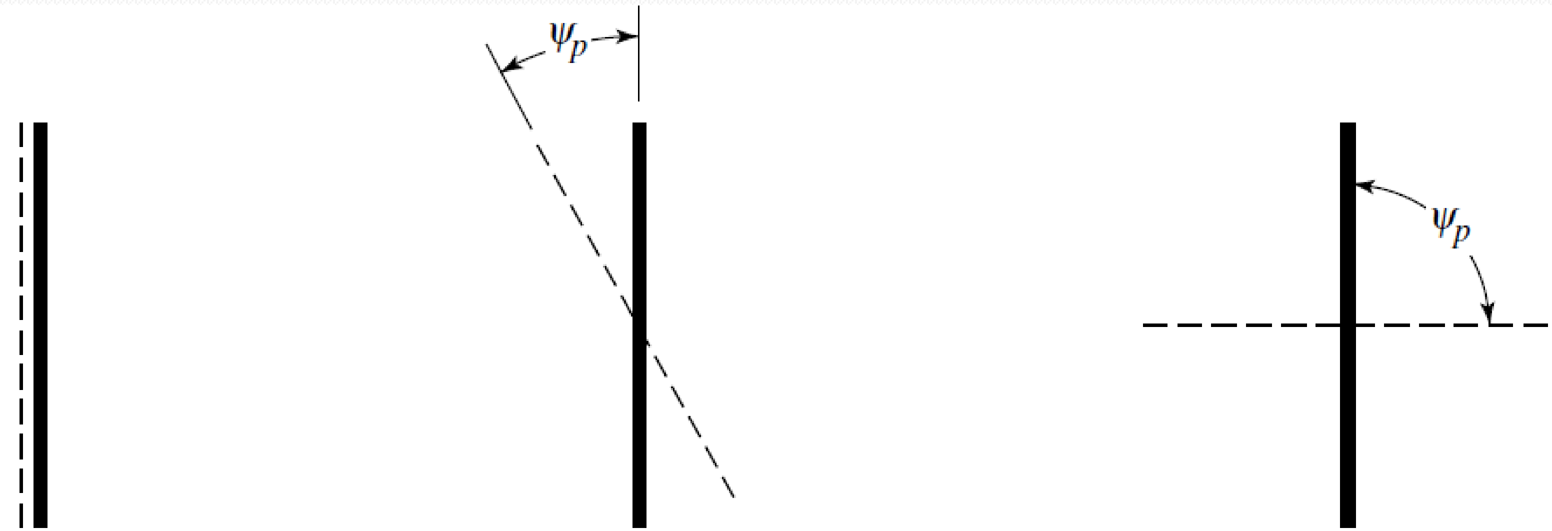
$\text{PLF} = |\hat{\rho}_w \cdot \hat{\rho}_a|^2 = 1$
(aligned)

$\text{PLF} = |\hat{\rho}_w \cdot \hat{\rho}_a|^2 = \cos^2\psi_p$
(rotated)

$\text{PLF} = |\hat{\rho}_w \cdot \hat{\rho}_a|^2 = 0$
(orthogonal)

Polarization Loss Factor & Efficiency

- PLF for transmitting and receiving linear wire antennas



$\text{PLF} = |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 = 1$
(aligned)

$\text{PLF} = |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 = \cos^2 \psi_p$
(rotated)

$\text{PLF} = |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 = 0$
(orthogonal)